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United States Marine Corps Expeditionary Rifle Squad Communications

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This CAPSTONE Report documents the Systems Engineering (SE) efforts of "Team Marine," from JAN 2009 to SEP 2009, in developing a recommendation to the US Marine Corps Systems Command (MCSC), on the best course of action to 'Enhance the USMC Expeditionary Rifle Squad Communications System.'

The squad leader is the cornerstone for USMC tactical operations. Clear, concise, accurate and reliable communications to and from the squad leader is the key to squad operations, performance and tactical effectiveness. Today's fielded communications system for the squad leader requires the use of two separate radios, each with different encryption algorithms, different user interfaces, and different data processing capabilities. This primitive design has thrust the squad leader into a complex Human Factors environment with disparate components that have not been well engineered or integrated.

Team Marine applied and tailored the systems engineering (SE) process based on NPS course work and professional experience. This SE process enabled the team to completely understand and model the current system in terms of architecture, capabilities and functions. The process led the team and stakeholders to conclude that an evolutionary approach of system integration was preferred over the traditional Manufacturer A vs. Manufacturer B run off.

The team's recommendation is to pursue an integrated communications system, based on existing and emerging components, as the best course of action. The first incremental step of the recommendation is to upgrade the existing elements by adding an automated communications processor with enhanced human to system interfaces.

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The United States Marine Corps (USMC) squad is the cornerstone for tactical operations. Clear, concise, accurate and reliable communications to and from the squad leader are the key to squad operations, performance, and tactical effectiveness. The squad leader is required to receive and accept tasking by higher authorities, request additional support as needed by available command elements, and must continually update and report unit status to other squad leaders and platoon commanders. All of these actions occur while simultaneously; communicating orders and intent, coordinating the movement of, and directing the actions of each individual squad member during all phases of operations.

Today's fielded communications system for the squad leader requires two separate radios, each with different encryption algorithms, different user interfaces, and different data processing capabilities. The squad members have one type of radio for inter-squad communications, while the squad leader has to carry an additional radio to communicate with higher echelons. This primitive design has thrust the squad leader into a complex Human Factors environment with disparate components that have not been well engineered or integrated. The squad leader must now configure, manage and communicate on two separate radios, while still being required to deploy and operate weapons.

This poorly integrated system has created an extensive, confusing, and costly logistics trail for the USMC to manage, since each radio requires unique power and peripheral devices as well as unique training. The lack of an integrated communications system affects day to day operations. Since each radio component is a stand-alone element, the squad leader's physical and mental workload is increased by processing data between two radios and up to 10 different radio circuits. Each USMC squad deploys unique configurations which are unable to communicate with nearby Joint and Coalition squads.

The Naval Post-graduate School (NPS) Cohort - Systems Engineering (SE) team, known as *Team Marine*, accepted the challenge of *'Enhancing the USMC Rifle Squad Communications System.'* The challenge originated from discussions with senior leadership from Marine Corps Systems Command, and the Program Manager for the Marine Expeditionary Rifle Squad program office. To meet the challenge, the team applied the NPS SE practices and analysis methods.

The System Engineering Design Process (SEDP) was used to understand the needs of the customer. Non-material alternatives were not considered to be viable to solve the capability problem. Four (4) possible material alternative solutions were developed to meet the customer requirements. These four alternative solutions were derived from the Functional Architecture, Physical Architecture, and Operational Architecture.

Through feasibility screening, modeling and simulation, decision scoring, risk analysis and cost analysis the team determined that an evolutionary development effort would be the best course of action for MCSC to undertake.

The team recommends the following course of action (COA):

1) In the near-term, pursue the Advanced Alternative. This alternative provides the squad leader with a fully integrated system comprised of wearable and hand-held sub-systems. The input devices are internal microphones for voice and touch screens for data input. The IISR (AN/PRC-153) provides a short transmission range of less than 3 kilometers with degraded capability and the AN/PRC-152 provides long transmission range that extends to 10 kilometers. This alternative is the best, "bang for the buck" integrated solution. As systems mature and technologies become available MCSC should be able to evolve the system into the Future Alternative.

2) PM MERS continue acquisition and development of the Advanced Alternative. Include the results of this team's effort as the foundation for future analysis, acquisition, and development.

3) Migrate to the Future Alternative when feasible.

I INTRODUCTION

A OBJECTIVE

The project's Systems Engineering (SE) team targeted a single integrated, interoperable, communications system capable of providing transmission relay, voice and data networking, and communications processing that can accommodate multiple levels of encryption and security among Marine, Joint and Coalition squads. The team's focus and goal is to 'Enhance the USMC Expeditionary Rifle Squad Communications System.'

B BACKGROUND

1. The United States Marine Corps

The United States Marine Corps (USMC) uses a multi-tiered and multi-faceted command element structure known as the Marine Air-Ground Task Force (MAGTF). The MAGTF is the premier expeditionary force capable of responding to conflict from the ground, air and sea. The MAGTF Expeditionary Force (MEF) is divided into a triad of functional command elements under the ultimate control of the MEF Commander. The USMC Operational View – 1 (OV-1), (Figure 1 below), depicts the three command elements which are the Ground Command Element (GCE), the Aviation Command Element (ACE), and the Logistics Command Element (LCE). Each of these functional areas is divided by echelon. (MAGTF C2 ICD, 2008)

Figure 1: MAGTF Operational View 1 (OV-1) (from MAGTF C2 ICD 28FEB2008)

The MEF command element is at Echelon I, (on the far left), and is depicted as a CAPSET I Combat Operations Center (COC). This tiered approach continues across the image to the right, down to the CAPSET V components, which includes the USMC companies, platoons, squads and teams.

The MAGTF structure allows the Marines to maximize their tactical advantage via a closely integrated air-ground and logistics team. A MAGTF can operate as an independent unit, part of a joint or combined task force, as a separate service component or as a uni-service force and can deploy by sealift, airlift or both. The MAGTF gives the Marine Corps a unique flexibility to respond rapidly to any contingency, anywhere in the world.

2. The Squad

The tactical operating concept for MERS was developed and defined through a series of operational scenarios which examined current and future employment concepts for infantry squads. This analysis assisted in identifying critical capability gaps associated with the status capabilities provided. The gaps are associated with the lack of

a networking capability able to convey Command and Control (C2) and Situational Awareness (SA) from higher to lower echelons of command. It was determined that this gap was critical to this effort and that the emerging networking solutions have to avoid becoming complex while still addressing the critical issues impacting the operations of the squad.

"The Marine Expeditionary Rifle Squad has been the basic building block for all Marine Corps operations and concepts since the birth of the Corps. The squad's organization and weapons have changed, but the squad continues to be the tip of the spear with the mission to locate, close with and destroy the enemy." (MERS CONOPS, 2009)

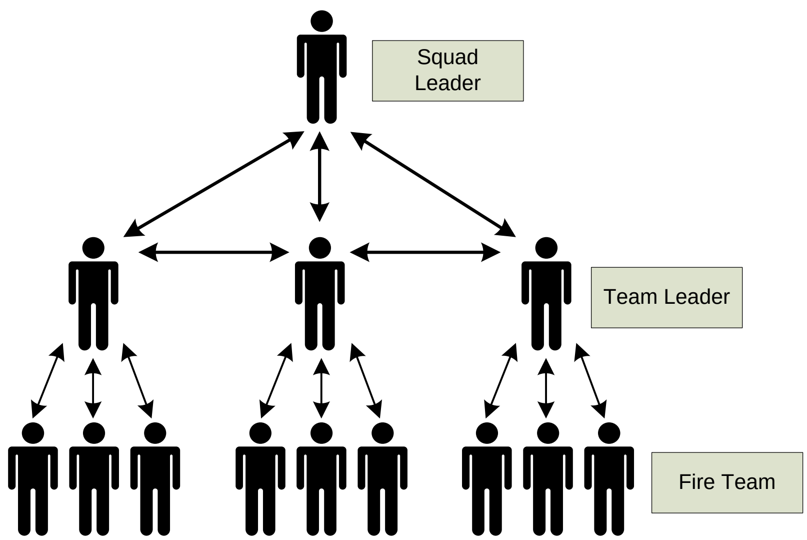


Figure 2: USMC Squad context

The basic mission of the MERS is to locate, close with, and destroy the enemy by fire and maneuver, or repel the enemy's assault by fire and close combat (MERS CONOPS, 2009). This basic mission never changes. However, the ability to execute the mission has grown increasingly complex, due to the introduction of more and more sophisticated technologies in a myriad of different operational environments.

MERS Tactical Operational Concept walked through the gamut of operational scenarios faced by the squad in order to examine current and future employment concepts

for the infantry squad and to identify any capability gaps. The analysis identified Command and Control (C2), Situational Awareness (SA), system networking and its ability to become increasingly complex and organic as critical issues impacting the operations of the squad.

"*Without the proper communications equipment, the squad will not have the capability to seamlessly communicate with joint/combined forces. Situational awareness will be lost and combined force effectiveness will be diminished. The potential for fratricide also increases.*" *(MERS CONOPS, 2009)*

3. Squad Communications

The expansion of information systems technology has fed the desire for greater communications and networking capability for the "last tactical mile" on the battlefield. This expansion has lead to the requirement for the ability of a Marine Squad to send and receive voice and data to higher, adjacent and subordinate personnel on the battlefield. Per the Joint Requirements Oversight Counsel Memorandum (JROCM 071-08), senior military leadership has determined that the data at the squad and below is mission dependent and may be either classified or unclassified. The JROC set forth the governing policy requiring forces operating in the battle space to employ capabilities that protect Position, Location Information (PLI). This can be accomplished via two levels of classification and encryption. Two-way, aggregate PLI data at the CONFIDENTIAL or higher level requires NSA approved Type I encryption methods. One-way, non-aggregate PLI data below SECRET must be protected at least as Controlled Unclassified Information (CUI), using NSA approved Type 2 encryption methods.

In practice, the Marine Corps has determined that both voice and data connectivity from the squad leader to higher echelons will be encrypted as Type 1 data. Additionally, the connectivity within the squad (squad leader to squad members) is considered CUI and must be encrypted as Type 2 data.

According to National Information Assurance (2006), a Type I device is an cryptographic equipment, assembly or component classified by National Security Agency (NSA) for encrypting and decrypting classified and sensitivity national security information when appropriately keyed. It is used to protect systems requiring the most

stringent protection mechanisms. A Type II devise is a cryptographic piece of equipment, assembly or component classified by NSA for encrypting or decrypting sensitive national security information when appropriately keyed. Type II classification is used to protect systems requiring protecting mechanisms exceeding best commercial practices including systems used for protecting unclassified national security information.

Both Type I & II encryption is developed using NSA business processes and contains NSA approved algorithms.

This decision and doctrinal approach introduces complex requirements that the currently fielded communications system cannot easily accommodate.

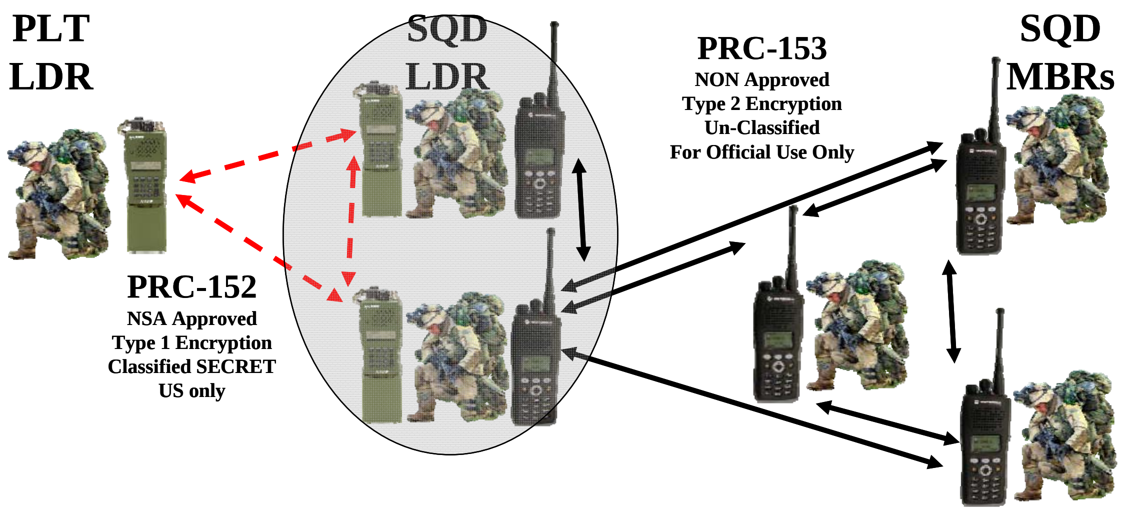


Figure 3: Current Squad level communication solution

The Marine Corps' currently fielded system was not engineered nor designed to address all of the JROCM memorandum requirements. Figure 3 above, identifies the two disparate transmission and encryption devices. The dashed - red arrows, on the left side of the diagram represent the two-way, classified, Type 1 encrypted data, which is passed among squad leaders and up to higher echelon authorities (i.e. platoon leaders). The solid - black arrows on the right side of the diagram represent the one way, Type 2, CUI data, which is shared among squad members and can be passed onto joint or coalition forces. This simple ad-hoc design lacks technical maturity and ignores many human factors. The configuration deploys two radios at the squad leader level; one is an AN/PRC-152 (Type 1 Encryption) for voice only communications between the squad leaders and platoon

commander. The other radio is an Interim Intra-Squad Radio (IISR (AN/PRC-153)) (Type 2 Encryption) for voice only communications between the squad leader and squad members.

The squad leader now has to carry, configure and operate two physical devices with incongruent designs and is still expected to carry out his combat mission, which includes engaging enemy forces.

C SCOPE, BOUNDS, AND ASSUMPTIONS

After defining the objective, the SE team developed the context diagram below in Figure 4. The diagram depicts the context of the system and intended system boundaries of this effort.

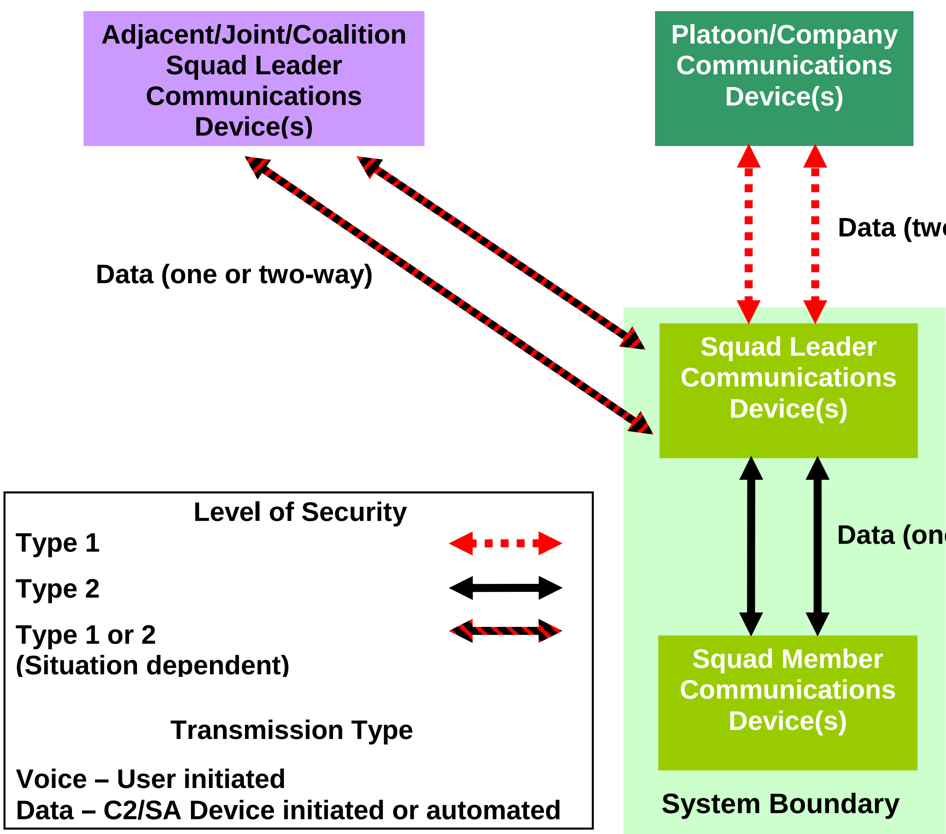


Figure 4: Communications System Context Diagram

Figure 4 also shows the information exchange relationships between the squad leader, the squad members, other squad leaders (both Joint and Coalition), and higher

command authorities. Physically, the system will be bounded primarily by the capabilities, configurations, and interfaces of the communications system for the Marine Rifle Squad Leader. The SE team further bounded the problem to concentrate on the communication system's processing capability and the corresponding human factors affecting the squad leader.

The critical assumptions and constraints for the project were determined and taken into consideration. These items aided the team in establishing the boundaries and scope of the problem description as the team labored toward an understanding of the effective need. The following assumptions were defined and used during the early phases of the effort:

- No overarching requirement documents exist for a squad level communications system in the USMC. Doctrine continues to mature and adapt to emerging technologies and capabilities. The Commandant of the Marine Corps published a document (A Concept for Enhanced Company Operations, 28 Aug 2008, Department of the Navy, Headquarters U.S. Marine Corps) to outline his plan for Enhanced Company Operations (ECO). As defined by the Commandant's concept paper, squad communications systems are a subset of ECO. As stated, "Tactical" units must gravitate from push-to-talk radio systems to mobile ad-hoc mesh networking." Marine Corps Combat Development Command (MCCDC) is the command assigned the task of rewriting and amplifying doctrine. MCCDC is currently taking several concept papers (like the ECO) and codifying these concepts into applicable doctrine. While this doctrine changes and adapts so do the technologies to realize the conceptual constructs and the informing doctrine.
- No documented requirement exists for an integrated system capability. The Programs of Record (PORs) that acquire and provide communication systems to the tactical users are not organized. These same PORs are also not mandated to coordinate their systems acquisition with other systems, either currently fielded or planned to be fielded. Without an integrated concept for the squad level communication system, the Rifle Squad will receive laptops

and /or Personal Digital Assistants (PDAs) from one POR, radios, Global Positioning System (GPS) units, and alternative power sources all from their own respective POR. It is important to note that an integrated capability (as defined by the analysis) is required in order for a successful solution to be implemented.

- The Joint Tactical Radio System (JTRS) is the DoD mandated provider of future tactical radios and associated waveforms. The JTRS Joint Program Office (JPO) is currently developing a family of radios that are software programmable to support service elements, joint and other agencies at the tactical edge. The available JTRS products today are considered a viable material solution for Marine squad leaders. The examination of the alternatives to support a non-material or material approach is vetted via this Systems Engineering Design Process (SEDP) during our analysis.
- The Blue Force Track (BFT) policy, approved by the JROC, requires joint communication standards. This policy defines the capabilities to establish and maintain connectivity for Command and Control and Situational Awareness nodes. It also mandates adherence to a common, friendly force, plain language addressing scheme between friendly forces operating in theater. The BFT architecture relies on a mixture of US government and commercially-leased satellites and ground control stations.

Other constraints listed below were used as entry criteria for the final system solution to be considered. MERS documentation, and input by Key Stakeholders led to these constraints being applied. Any potential alternative system had to meet the following conditions:

- Operate in Military Spectrum Bands (per FCC guidance)
- National Security Agency (NSA) certified or certifiable
- Joint Integrated Test Center (JITC) certified or certifiable
- JTRS Service Component Architecture (SCA) 2.2 compliant
- Requires no Satellite Communication (SATCOM) equipment at the squad level

- Power system must support Mission Duration times no less than 8 hours
- Total system weight must be lighter than the currently fielded system configuration
- Operate independent of commercial telecommunications infrastructure
- Total Research, Development, Test and Evaluation (RDT&E) costs must be less than current PM MERS program funds
- Initial Operational Capability (IOC) in accordance with PM MERS acquisition documentation
- Full Operational Capability (FOC) in accordance with PM MERS acquisition documentation
- Backwards compatible with existing systems until FOC

D SYSTEMS ENGINEERING METHODOLOGY AND APPROACH

The Systems Engineering Methodology for the Squad Communication System was a tailored process adopted from original ideas and various existing systems engineering models. Models, concepts and methodologies include the Traditional Structured Analysis Model (Grady, 2009); concepts for functional, physical, and operational architecture development from D.M. Buede (Buede, 2000); and environmental classification definitions by Grady (2009). When these concepts were combined, a roadmap from a user need to a recommended alternative was developed to focus the team's analysis. This roadmap provided the framework and direction of the effort, from need, concept development, alternative analysis and finally a recommended solution for the Rifle Squad Communication System.

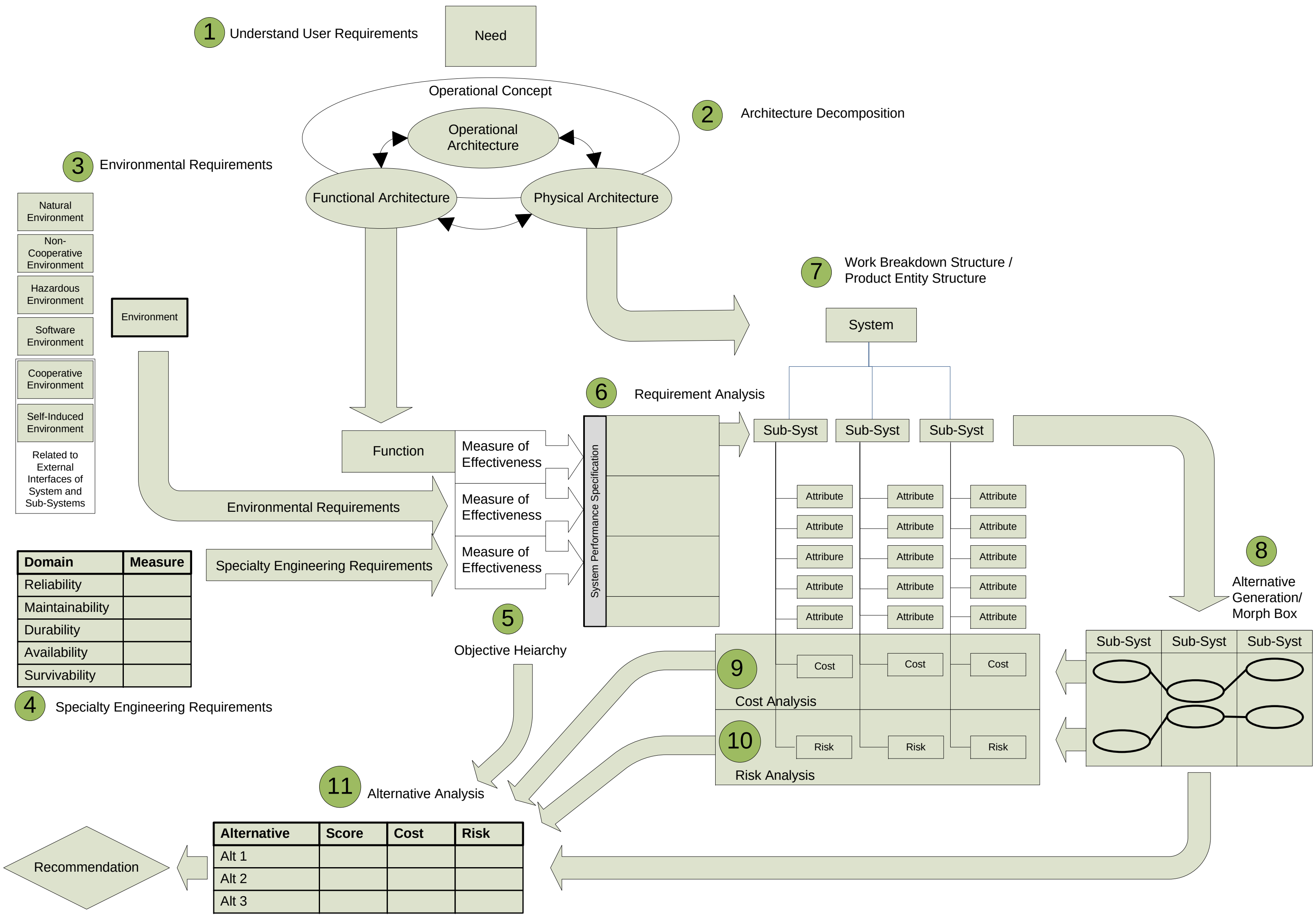


Figure 5: Detailed Systems Engineering Process

The methodology begins with understanding the user requirements 1. This includes the development of a preliminary problem statement that assesses what the user perceives as the need to perform operational tasks, the conditions in which they perform them, gaps in the current system, and inferences about the future state. These inputs help formulate needs and constraints of the system, the operational context in which it must perform, and the preliminary assessment of system boundaries. With this information, an intensive architecture decomposition effort can further define these contexts. The architecture development 2 involves the operational, functional, and physical decomposition to further develop the context of the system and create the basis of performance requirements while being bounded by the Operational Concept. The end result of this decomposition is a well defined functionality that the system must fulfill within the larger context of the Marine Corps and a work breakdown structure 7.

In parallel to the sub-system definition, a complete analysis of the intended environments 3 and specialty engineering aspects 4 of the system will give sufficient depth to the requirements development. The breadth of environments include internal environments the system itself creates, external environments that the system operates in, and interfacing systems beyond the scope of the system that is being defined. Specialty engineering aspects are captured to envelop the higher system level requirements that are not captured within the decomposed functions For example, system reliability, maintainability and survivability are defined at the highest system level and then flowed down to the sub-systems in future iterations. These specialty engineering aspects also bound the system tradespace to work within the established USMC maintenance, logistic, and supply system. Environment and specialty engineering analysis make up the non-functional portion of the objective hierarchy.

When the functional and non-functional requirements converge, Measures of Effectiveness (MOEs) are developed for all requirements to make up the Objective Hierarchy 5. These MOEs are the basis of a system level performance specification or capabilities development document (CDD). However, for the purposes of this analysis, an Objective Hierarchy will be sufficient to complete the methodology. The

requirements analysis[6] provides the complete linkage between the measures of effectiveness and allocation to a sub-system developed from the physical architecture. This linkage is the key to future refinements of the system beyond the early concept phases of the program. This helps provide a foundation for good systems engineering and a backbone for sound program management.

From the high level description of the sub-systems, (defined from the architecture decomposition and the physical architecture)[2], the system is then decomposed into the next layer of abstraction, where actual hardware elements are assigned to the physical architecture. Ideally all the system needs, defined in the objective hierarchy, are represented by the hardware elements. Alternative Generation[8] is developed using a morphological box or similar brainstorming exercise to ensure all ideas are considered. Alternatives are screened for feasibility and grouped together to make a complete system as described in the physical architecture. At this point in the methodology, the hardware chosen to make up the system can be analyzed for cost [9] and risk[10] to contribute to the alternative analysis[11]. A completed alternative analysis will result in a recommended alternative. This methodology is an iterative process that is the foundation for future systems engineering work as the system undergoes further definition to the component and sub-component level. This methodology also provides the necessary roadmap and traceability when requirements evolve as the needs of the Marine Corps evolve.

II PROBLEM DEFINITION

During the Problem Definition phase of the design process the team focused upon interdisciplinary methods for defining a vision of what constitutes a system, in terms of meeting the stakeholder needs. Problem definition is crucial as it establishes the basis for all subsequent analysis and evaluation of the project.

A PROBLEM STATEMENT

Joint Requirements Oversight Counsel Memorandum 071-08 directs for U.S. Forces to explore alternatives for enhanced communications and networking. It also identifies the need for an enhanced Blue Force tracking capability for Command and Control (C2), and Situational Awareness (SA) that supports seamless exchange of information between operating forces in joint operational areas. (Note: Blue Force tracking is a United States military term used to denote a Global Positioning System (GPS) enabled system that provides military commanders and forces with location information about friendly military forces).

This memorandum addresses a need to promote sharing of secure/unsecured position location information and relevant SA information between combatant commanders, services, and agencies. Senior level leadership has determined that squad level and below communications are mission dependent and may have varying levels of classification; therefore, the telecommunications devices used by the squad must also be able to satisfy all missions. In addition, current programs fall short of supporting a MERS net centric capability today. The challenge now for the Marine Squad Leader is executing the mission effectively as a maneuvering element of the rifle platoon with the existing "status quo" communications solution. The primitive need of this project focuses on finding a system that could adequately address the command and control and situational awareness capability required by the Marine Corps.

B NEEDS ANALYSIS

1. Stakeholder Analysis

Requirements are generally considered the cornerstone of the systems engineering process. Originating requirements are those requirements initially established by the system stakeholders with the help of the systems engineering team. The systems engineering design process is a mixture of establishing requirements to define the design problem and portioning the physical resources of the system into components that perform functions that meet the requirements. Many important decisions are made by the systems engineering team that will ultimately affect the performance of the system and the satisfaction of the stakeholders. (Buede, 2000)

A stakeholder analysis was conducted to gain a better understanding of the needed capability and determine customer desires from a holistic view, with the goal of addressing joint and service requirements.

a. Stakeholders

The stakeholders that have a vested interest have been identified from the following groups of clients, decision-makers, sponsors, users, and analysts. The key stakeholders for this undertaking were determined to include, but are not limited to the following organizations:

(i) Policy & Decision Makers

- Joint Forces Command (JFCOM) oversees joint services transformation including Concept Development and Experimentation, Training, Interoperability and Integration according to Unified Command Plan (UCP) (2008). JFCOM helps develop, evaluate, and prioritize the solutions to the interoperability problems plaguing the joint war fighter.
- Headquarters Marine Corps (HQMC) Command, Control, Communications and Computers (C4) is responsible for the planning, directing, coordinating and overseeing, C4 and Information Technology (IT) capabilities that support the warfighting functions, and influences the combat development process by

establishing policy and standard for developing the enterprise architecture to achieve Joint and combined interoperability. (http://www.hqmc.usmc.mil/PP&O)

- HQMC Plans Policies & Operations (PP&O) is responsible for the coordinating the development and execution of service plans and policies related to the structure, deployment and employment of Marine Corps forces. (http://www.hqmc.usmc.mil/PP&O)

(ii) User Representatives

- Marine Corps Squad Leader is responsible for carrying out missions communicated to him by his Platoon Commander through the effective management of the squad and squad resources.
- Marine Corps Combat Development Command (MCCDC) is responsible for the development of fully integrated Marine Corps war fighting capabilities; including doctrine, organization, training and education, materiel, leadership, personnel, and facilities, to enable the Marine Corps to field combat-ready forces. (https://www.mccdc.usmc.mil).

(iii) Acquisition Agents and System Developers

- Marine Corps Systems Command (MCSC) Deputy Commander, Systems Engineering, Interoperability, Architectures and Technology (DC-SIAT) serves as the principal agent for acquisition and oversees the development of the complex systems that equip today's Marine force. (http://www.marcosyscom.usmc.mil/sites/siat).

(iv) Evaluators & Analysts

- Marine Corps Operational Test & Evaluation Activity (MCOTEA) provides operational testing and evaluation on behalf of the Marine Corps and conducts additional testing and evaluation as required to support the Marine Corps mission to man, train, equip, and sustain a force in readiness.

- Marine Corps War-fighting Laboratory (MCWL) improves current and future naval expeditionary warfare capabilities across the spectrum of conflict for current and future operating forces.

b. Stakeholder Approach

The approach for capturing the stakeholder needs included questionnaires, interviews, and research that determine the values germane to transforming the primitive need statement. A questionnaire (in APPENDIX D) was designed to facilitate describing the problem from points of view from all stakeholder groups. The stakeholders provided responses. Research of source documents was also incorporated within an affinity diagram, which was used to arrange and group ideas.

c. Policy Makers

Research of policy documents produced a joint operational capability with respect to the problem space of marine expeditionary rifle squad communications. The JROC approved position location information (PLI) classification and security policy for blue force tracking system determines a need for C2, and situational awareness at the edge of the battle field. The policy guidance for the marine squad communications system is traceable back to the following joint capability requirements:

- Forces using two-way C2/SA systems must protect aggregated BFT PLI data at the confidential or higher level of classification. All devices operated at this level that transmit and receive aggregated PLI data must be designed to protect this data to a level merited by classified information.
- PLI classification is mission dependent. PLI may be either unclassified or classified depending on mission and combat conditions.
- Friendly force units operating in a battlespace or other combatant commanders declared operating area must employ capabilities that protect exploitable (nonperishable, survivable) PLI data as classified.
- Both transmission security and crypto logical security are necessary to protect a PLI system or family of systems from exploitation.

- PLI systems should be designed to optimize both types of security. Combatant Commanders may establish particular mission-dependent guidance applicable to generation, transmission, and handling of PLI data for forces operating in the air, space, maritime, and ground domains.
- Forces may protect one-way, non-aggregated PLI data to less than secret, but as a minimum must protect to the level merited for controlled unclassified information (CUI), and certified by NSA.

d. Acquisition Agent Feedback

Examination of Marine operating concept source documentation illuminated an operational capability that meets the needs of the USMC for MERS communications. Specifically, squads require advanced, integrated, and multi-purpose systems for communication, location, and identification. These assets must be capable of calling for fires and coordinating with other physically separated units moving throughout an expanded battlespace. Focused, realistic and demanding training is probably the single most critical element for development of rifle squad capabilities. The squad leader and fire team leaders require more robust and expanded training in several critical areas to ensure they develop the independence, self-reliance, and confidence to handle more demanding situations. Maneuver units and fire support assets must be able to identify small friendly units distributed across the battlespace. (MERS Draft Tactical Operating Concept, 2009). The following were recommendations from the acquisition agents:

- Develop an Initial Capability Document (ICD) for MERS
- Create a formal Program Objective Memorandum (POM) initiative for MERS
- Continue dialog with the operational forces to identify evolving needs
- Continue socializing the concept to USMC leadership
- Develop Capability Development Documents (CDDs) to identify the highest priority required capabilities as determined by the war fighter input

e. Clients and Users Feedback

Questionnaire responses from the user community gave insight on the communications solution of today, and provided feedback on additional capability desired by the end-user. The current communication capability fielded has two radios for the squad leader to conduct communications vertically, and horizontally. The first radio is a AN/PRC-152 with NSA approved encryption for voice only communications between the squad leaders and platoon commander. The second is an Interim Intra-Squad Radio (IISR (AN/PRC-153)) with commercial encryption for voice only communications between squad leaders and squad members. This communication approach has its drawbacks from an integration stand point because of the additional devices required to conduct communication during missions.

The following desired capabilities were identified by the users:

- A tracking capability for infantry units is a necessity for situational awareness back to command.
- The Marine squad missions now call for a non-terrestrial multiband waveform based capability for interoperability between various communications devices
- A common encryption scheme to reduce logistical requirements
- A data information sharing capability is needed for non-verbal information exchange
- Interoperability between coalition, service elements, and other agencies for joint missions
- Ruggedized equipment with enhanced durability for different operational environments.
- Training, ease of use, ergonomics, for communicating rapidly
- Current implementation requires multiple devices to conduct operations.

f. Evaluators and Analysts Feedback

The project team conducted a Human Factors Engineering Analysis on the currently deployed primary squad level radio (AN/PRC-152) to determine the usability from a Squad Leader perspective. The goals of the analysis were to identify causes of increased human error, task time, and workload.

Today the USMC Squad leader is mentally over-tasked and physically over-burdened. The execution of the missions requires communicating the orders for the tactical employment, fire discipline, and fire control of the squad during close engagement with the enemy. The analysis recognized human factors challenges to include:

- There is no formal training provided to the user for the IISR (AN/PRC-153) radios. The platoon level and below (Users) are often given on-site informal training as needed or during exercises and are given a comprehensive manual with the radio, for reference.
- The Liquid Crystal Display (LCD) on each of the fielded radios lacks an antiglare protection which makes the black text on a green or gray background hard to read in bright sunlight. In addition, both radios use different font sizes and the smallest font characters are extremely difficult to view unless the radio is held closer to one's face.
- The weight and size of the AN/PRC 152 radio is approximately 2.6 lbs. without the whip antenna, and approximately 3.3 lbs. with the antenna. This device is top heavy when held in the middle with one hand, which creates a torque effect on the wrist. A holster is used primarily once the radio is configured.
- The channel selection and transmission switch are difficult to view in low level lighting. The switch is not illuminated for night missions, and the encryption type that the radio uses is not intuitive.

2. Affinity Diagram

The results of the team's research and interviews with key stakeholders enabled the needs analysis effort and resulted in focused information gathering. An Affinity Diagram is used to organize and group information. The process began with the generation of feedback from the stakeholder interviews. The feedback was displayed for the sole purpose of searching through the data with the premise that similar ideas were grouped together and unrelated feedback established new groups. The ideas that are similar were added to the same groups, and unrelated feedback established new groups.

The *"Improvement of USMC squad to share and communicate"* affinity diagram is seen in Figure 6 below.

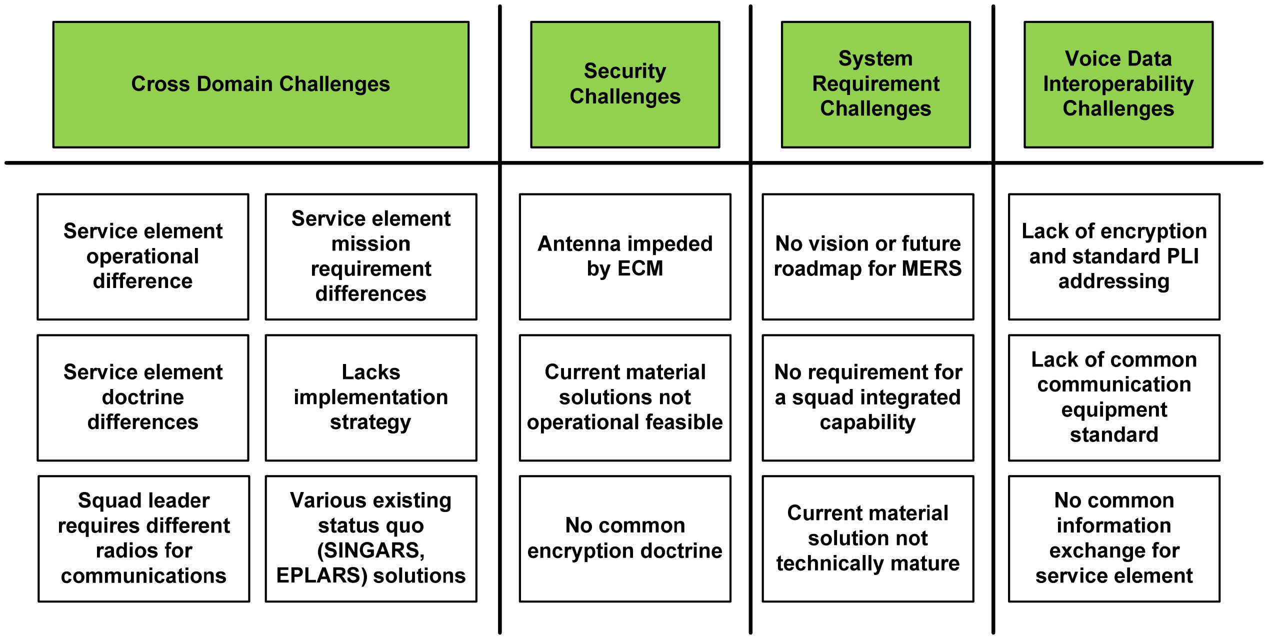


Figure 6 Affinity Diagram

3. Effective Needs Statement

After fully examining the results of all of the needs analysis tools, the team developed the following effective needs statement:

The Marine Corps requires a device or devices that will equip the squad leader and members with the ability to communicate key information exchanges to perform their mission. The communications equipment must meet doctrinal mandates and provide reliable, covert, secure, timely and accurate information when and where needed.

Key verbal and non-verbal information exchanges are:

- Geographic location / Position Location Information (PLI)
- Mission objectives / Commanders Intent and Orders
- Personnel status, equipment status, weapons and ammunition

4. Input-Output Model

The system must meet the minimum capability to transmit, receive, and process voice communications with input via a microphone and output via a speaker. Based on the effective need statement above, the system must also provide the additional capability to transmit, receive, process, and display digital data, in textual and graphical representations. For example the system must display and transmit the member's PLI with latitude and longitude readings. The system must also provide additional networking capabilities, or connectivity in order to support a suite of other netted sub-systems, Command & Control (C2) and Situational Awareness (SA) systems or devices, (such as a personal processing device, a BFT system, Marine health monitoring devices and weapon monitoring devices, etc.). These additional devices must be able to interface with the system but are not considered part of the transmission system. The devices must operate in combat conditions, requiring the ability to control light emitted and the ability to increase or decrease audio output.

In **Error! Reference source not found.** below the team developed a simple view of the inputs and outputs of the communication system at the squad level. This view provides a partial list of controllable and uncontrollable inputs and their respective outputs after the system has processed them. This list is not all inclusive but is a focused set of parameters based on existing communications systems in the current operational environments today. Currently the fielded system only processes voice communications as the input into an audible output.

Ultimately the squad communications system will provide the squad leader the ability to receive, transmit, generate and process both voice and digital data sets of information simultaneously, (i.e. formatted message sets, free text or chat, GPS coordinates, etc.).

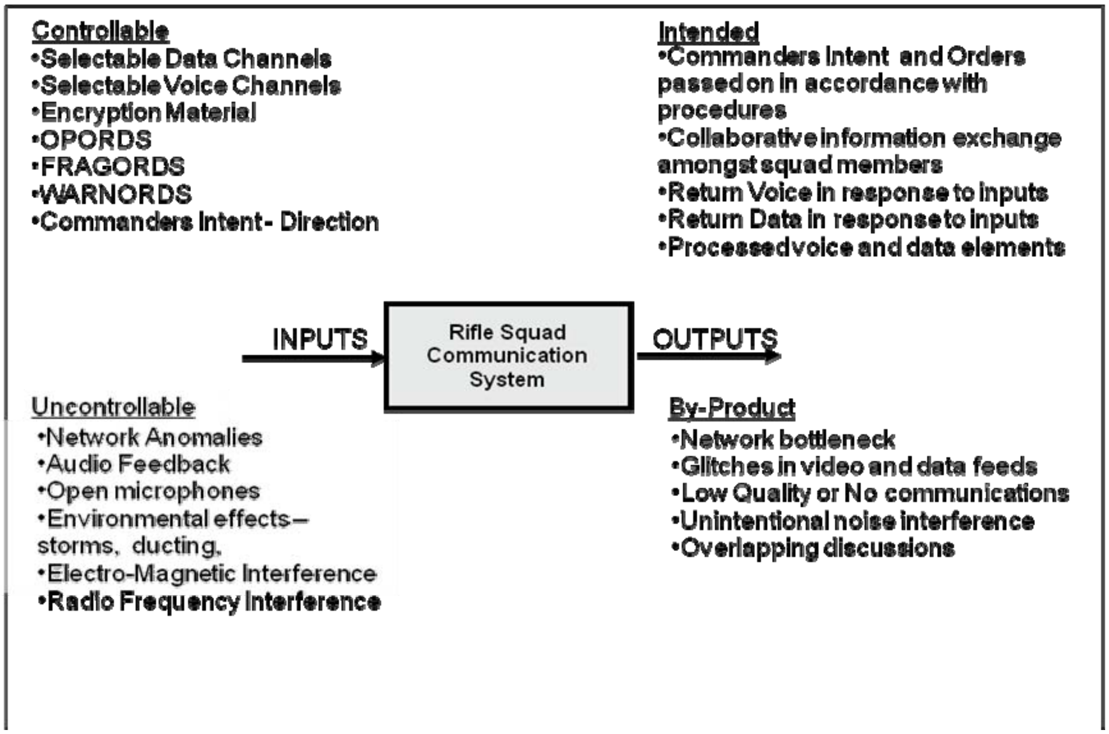


Figure 7: Input – Output Model

For example, the system should receive a digital image with annotated text while the squad leader is using his or her voice to update the squad's current position to the platoon commander. The desired output of this example is an error free image received as well as a clear, un-garbled audio message acknowledged by the platoon commander. Other parameters listed in the diagram are described below:

a. Controllable Inputs:

The operator must have the ability to select one or multiple channels to accomplish voice and data transmissions across directed radio and networking channels. This operation can be pre-planned, automated, or manually applied based on operator requirements.

The encryption material will be in the forms as designated by NSA and in keeping with common operating Tactics, Techniques and Procedures (TTPs). The physical inputting of the encryption algorithms may be automated or manually inserted.

Data sets with formatted descriptive elements, such as Operational Orders, Fragmentary Orders, Warning Orders and Free Text Messages will be created or

published. These data sets will be created or published by other Command and Control / Situational Awareness (C2/SA) devices in digital formats applicable to wireless transmissions. For the purposes of this project it will be assumed that these C2/SA devices will interface with a network capable radio/transmission device.

Additional information systems relying on an available network capable system could include automated Weapons Systems Status, Individual Health Monitoring, and other systems reporting details relevant to the operating environment. Inputs will be enabled via networking interfaces like Universal Serial Bus USB, Ethernet, and Serial ports.

b. Uncontrollable Inputs:

With all digital transmission systems, the introduction of networking anomalies, audio feedback, environmental effects, and electromagnetic effects must be anticipated and the transmission system must be able to overcome and adapt to the challenging networking environment as experienced on the battlefield.

c. Controllable Outputs:

Outputs will be enabled via networking interfaces. As a result of the ability to transmit and receive digitized voice and data, the system output will be audio or data elements translatable by the system or netted sub-systems. These received and processed data and voice elements will result in individual and unit C2/SA capabilities. The voice digital outputs will be formatted for direct audio output to speaker system. The data digital outputs will be formatted for direct translation to connected individual C2/SA devices. At a minimum the system must be able to transmit process and receive all formatted audio transmissions and formatted position location information (PLI).

d. Uncontrollable Outputs:

Cross-talking circuits, network interruptions, garbled or unreadable data and other data elements can be expected for devices operating in this environment. The system must be able to overcome these obstacles but the processing and data formatting are again resident in the network sub-systems and not a required capability of the communication system.

The IO model in Figure 7 provided the SE Team another tool that described the basic information flow of data and the basic functions expected of the communications system at the squad level. In other words the team used the IO model to determine, ‘What does the system need to do?’ rather than try to resolve ‘How does the system do it?’ The description of the system then allowed the team to move forward into the functional analysis.

III DESIGN

A FUNCTIONAL ANALYSIS

The end state of the functional analysis was to establish an operational, functional, and physical architecture of the squad communication system in order to provide traceability to the user requirements and operational context of the system. This is accomplished through several decomposition iterations of the three architectures throughout the systems engineering methodology. All three architectures represent the logical model that D.M. Buede describes as the transformation of inputs into outputs. (Buede, 2000). Through several iterations, the logical model is better defined at lower levels of abstraction. These lower levels of abstraction describe the intricate nature of the system. With well defined logical models, the system description can evolve when the environment, requirement, or operational context changes to maintain relevance. The logical models were developed with a tailored Integration Definition for Function Modeling (IDEF) technique to graphically convey these relationships of inputs and outputs. (National Institute of Standards and Technology, 1993).

The three architectural views of the squad communication system are essential to form the context and objectives of the system. The functional and physical architectures closely followed the definition established by D.M. Buede as a decomposition of the function to which the system needs to perform in order to meet the needs of the operational architecture. (Buede, 2000). The operational architecture used in the analysis, which is consistent with D.M. Buede's three architectural view framework, was a hybrid development based more closely to the Department of Defense Architectural Framework (DODAF) Operational View. This operational architecture approach improved traceability to the system of systems architecture from the MERS ICD and architectures. The MERS system of systems architecture (Figure 8) becomes the platform to align functions performed by the Marines within the operational context. A hybrid approach ensured consistency and traceability to the larger system of systems view.

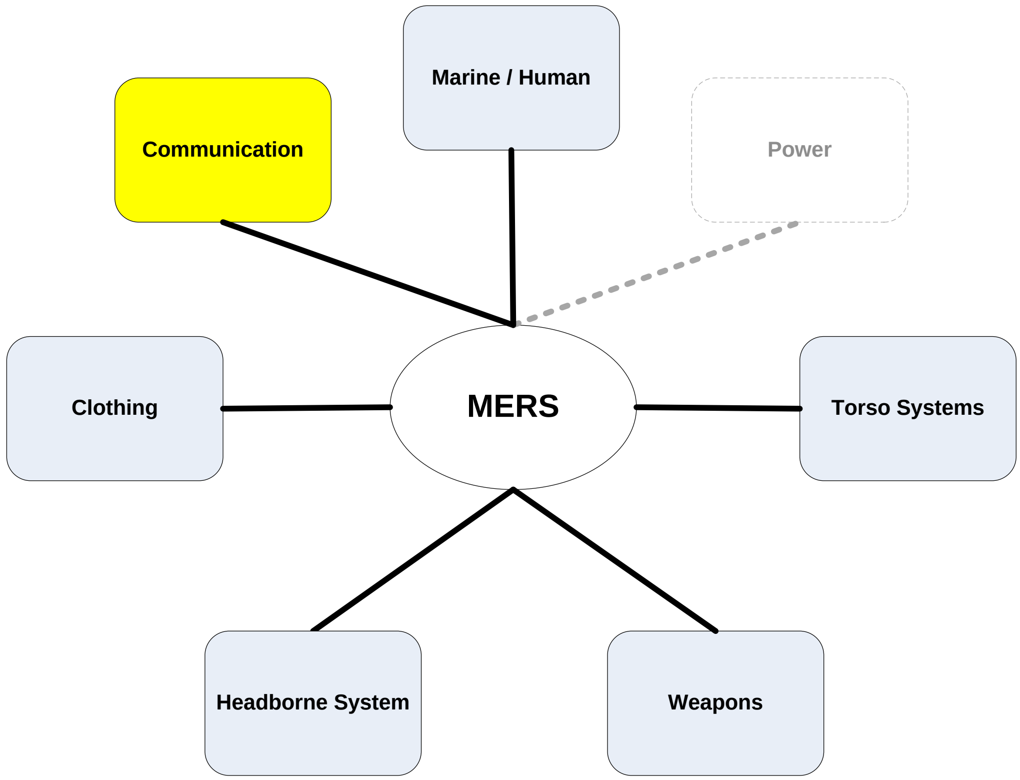


Figure 8: MERS System of Systems Architecture

1. Operational Architecture

The Operational Architecture provides the purpose of the system within the operational context. The Operational Architecture is the graphical decomposition consistent with the DoDAF Operational View Three (OV-3) which describes the relationships, information flow, and information content. (Wisnosky, 2006). These are the critical information exchanges that the communication system must process to carry out the missions defined in the MERS Architecture. (MERS Architecture Final Practicum Project Report, June 2008). Missions are defined in this study as the tasks, together with a purpose, that clearly indicate the unit's actions to be taken. ("Joint Publication," 2009). The Operational Architecture defines the required minimum communication messages that the Marine Squad Leader must process to provide command and control of the squad fire teams and the necessary communications to higher headquarters. This information exchange contributes to the Common Tactical Picture (CTP) during all missions.

The required communication messages and functions used for the Operational Architecture were allocated and decompose from the higher level communication

function in the MERS Architecture. The Operational Activity Model (OV-5) (See APPENDIX C) provided the activities or functions, while the Operational Information Exchange Matrix (OV-3) (See APPENDIX C) provided the information exchange or communication messages required to perform these functions. (MERS Architecture Final Practicum Project Report, June 2008).When the OV-3 and OV-5 communications functions were developed in modified IDEF models the inter and intra-nodal relationships helped shape the necessary functions to process the communication messages effectively. For example, a majority of messages in the operational architecture require a geographic position of the squad and fire team. Therefore at the system view, the communication system needs to have a global position function to carry out the operational function or needs a defined interface to another MERS system that will perform that function. Functions such as target location, ammunition status, and equipment status were allocated to other MERS systems, and are not within the boundary of the communication system.

The operational view was also used to define the different levels of classification required when sending messages. The need for cryptographic material was defined in the problem definition, but the operational architecture provides a mental model of the relationships for each level of classification required. Figure 9 shows the inter-nodal diagram of the Marine squad with the different levels of cryptographic material needed to provide secure communications. (MERS Architecture Final Practicum Project Report, June 2008)

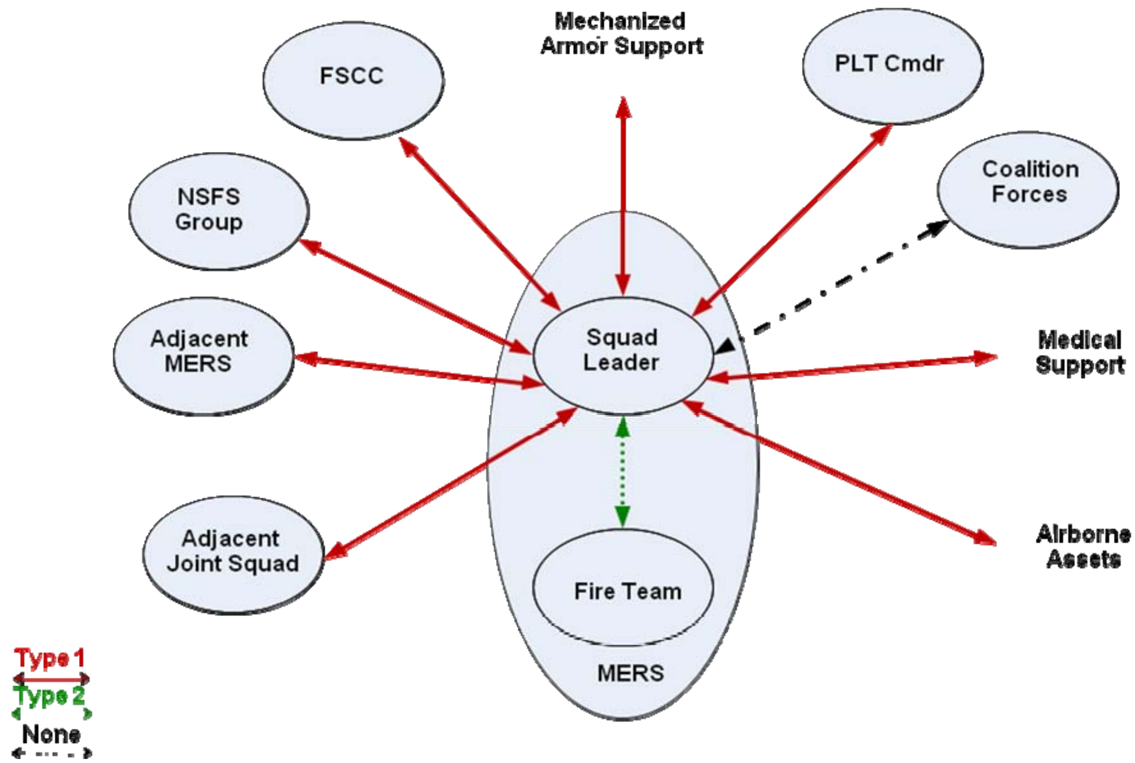


Figure 9: Operational View Inter-nodal Diagram

The Squad Communication System Operational View A0 (Figure 10) models the inputs and outputs of the various messages required for the squad to be an effective part of the CTP and supply sufficient command and control of the squad. The messages identified in Figure 10 are the minimum set of structured messages. Communication takes many forms and cannot be accurately accounted for in the system, but can be grouped sufficiently under the communication messages modeled.

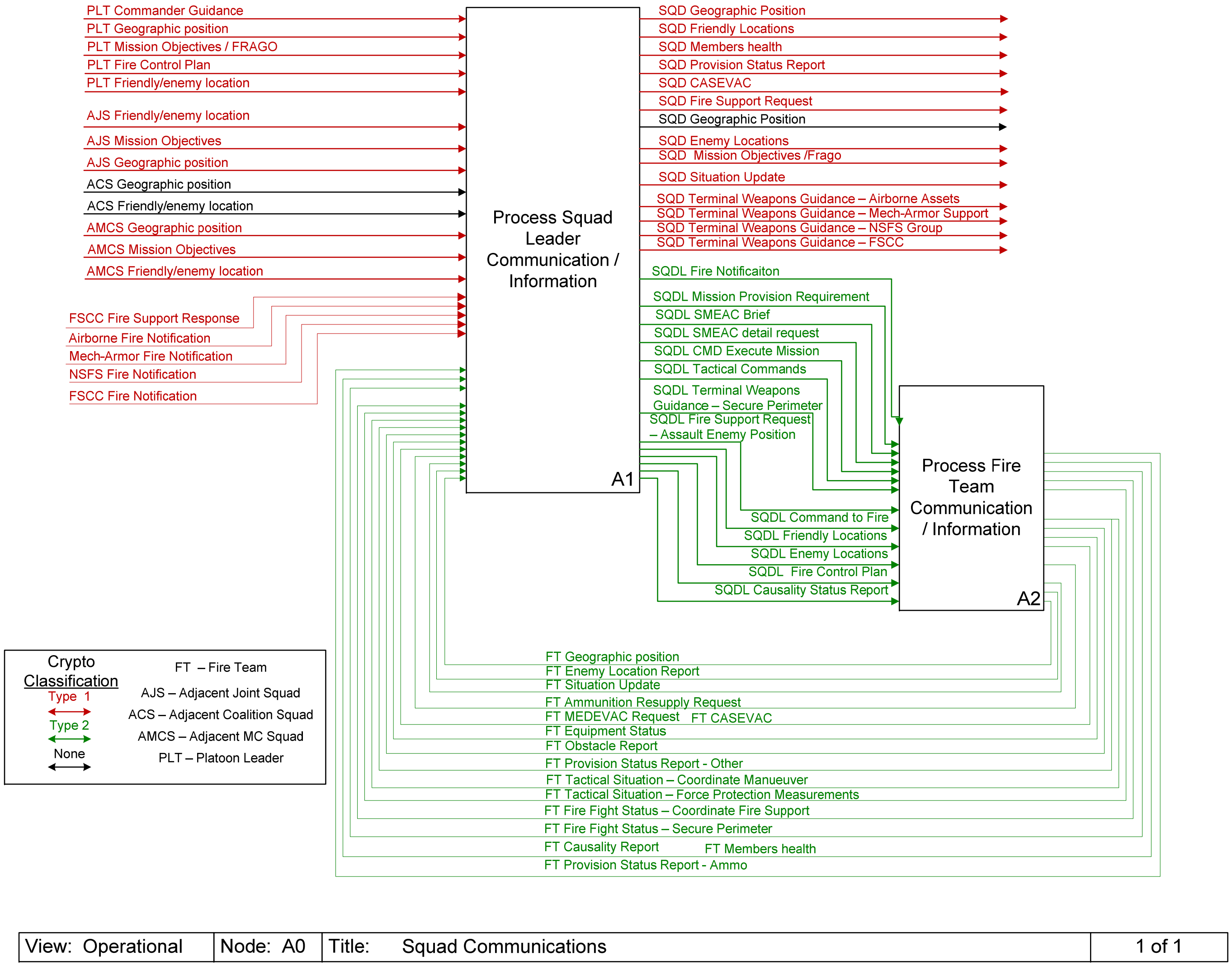
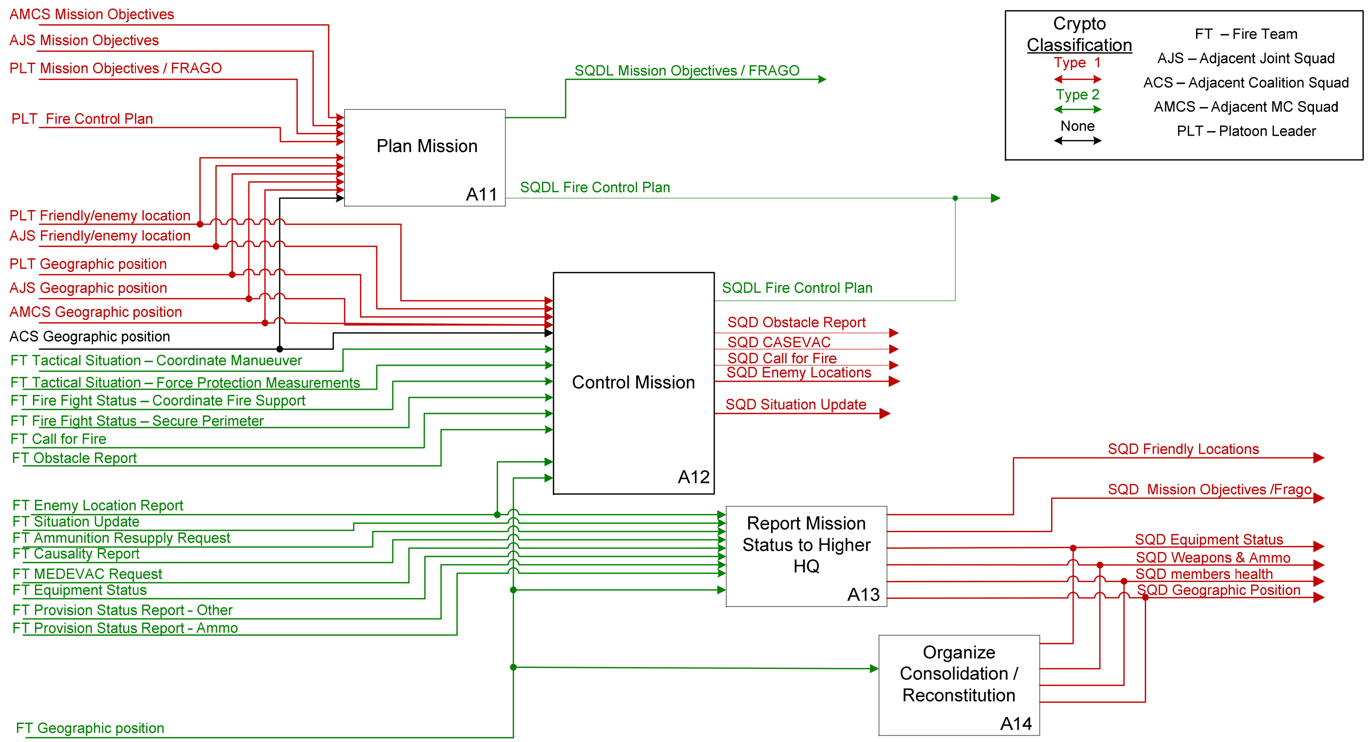


Figure 10: IDEF-0, Operational View, A0

The primary operational function for the squad communication system is to Process Squad Communication/Information. This can be decomposed into two functions: Process Squad Leader Communication/Information and Process Fire Team Communication/Information. It is assumed that both the squad leader and fire team will have common systems and equal capability to process messages. The inputs to the squad leader are messages across the range of nodes depicted in Figure 9. This squad leader function transforms messages into actions to perform the required missions of the Marine Squad. The required missions were defined as functions at the next layer of abstraction as seen in Figure 11 Operational View A1. By doing a complete decomposition, all required messages to perform the mission function were identified.

These communication messages are not defined as voice or data, but have the same information attributes regardless of the message form transmitted. The forms will remain generic throughout the functional decomposition in order to allow an open approach to alternative generation. Depending on the alternative, either form may be used. The Operational View A1 (Figure 11) decomposes block A1 to four functions: Plan Mission, Control Mission, Report Mission Status to Higher Headquarters, and Organize Consolidation / Reconstitution.

The complete Operational Architecture is located in APPENDIX E. Since the Fire Team is the major action unit for the mission, the A2 block was decomposed to the next level of functional abstraction. At the fire team level, the focus was limited to Marine squad missions of Movement to Objective (by foot), Linkup, Reinforce, Passage of Lines, Infiltration, and Obstacle Crossing/Reduction as defined by the MERS Architecture OV-5. Other MERS missions of Movement to Objective via Ground, Amphibious, and Air Vehicles were not evaluated because it is assumed the host vehicle will support the required communication functions until the squad is dismounted.



View: Operational	Node: A1	Title: Squad Leader Communications	1 of 1

Figure 11: IDEF-0, Operational View, A1

2. Functional Architecture

The operational view defined the communication messages exchanged for each mission. The functional architecture defines how the system will process those communications messages. The functional architecture will be allocated to the physical architecture and will define the squad communication sub-systems.

The Functional Architecture A0 (Figure 12) was used to answer:

- How will the system processing incoming messages, decipher data, and convey to the user?
- How the system will generate the required data and send messages to the various nodes described in the Operational View Inter-nodal diagram?
- What are the required internal and external interfaces?

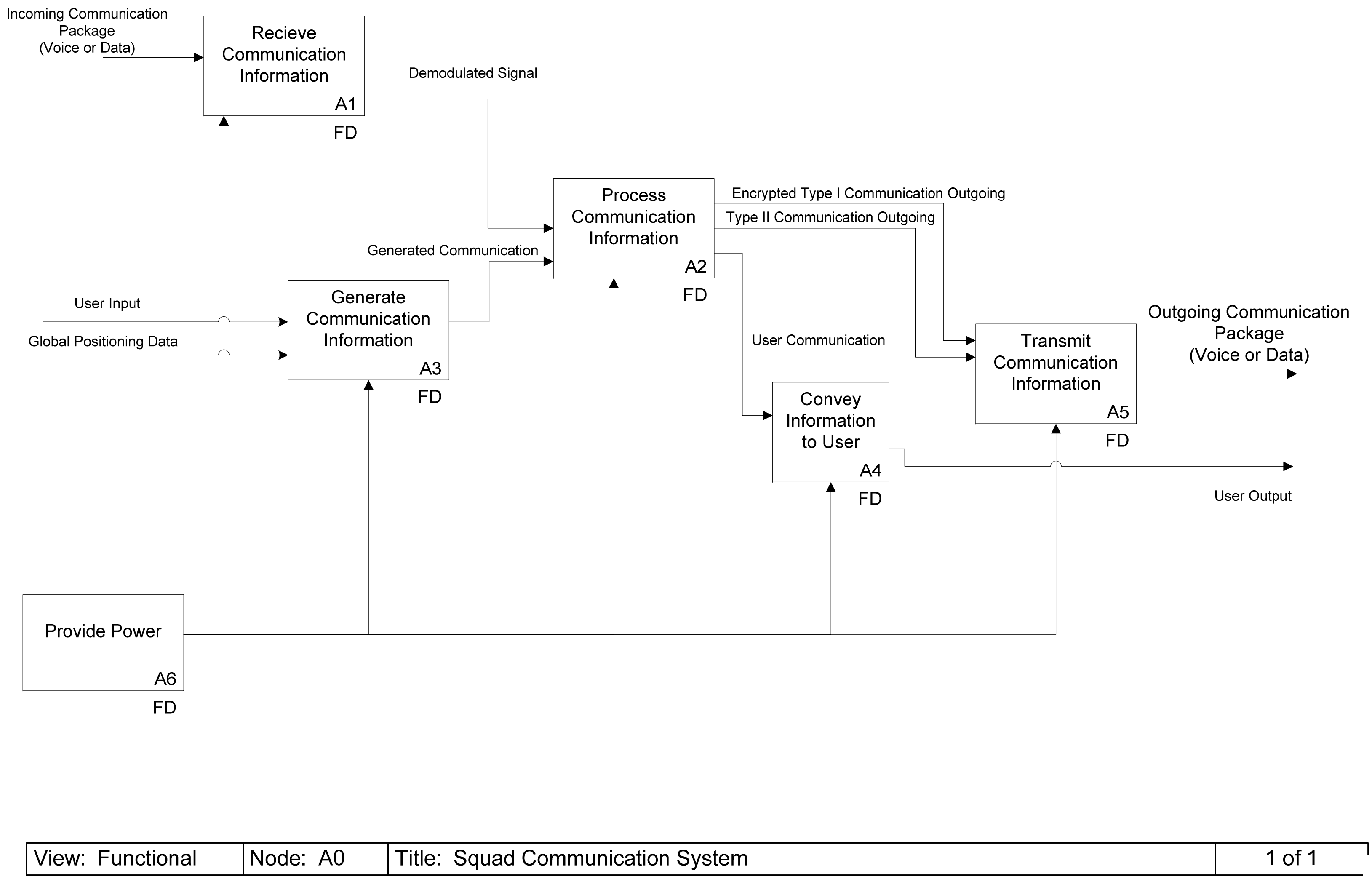


Figure 12: IDEF-0, Functional View, A0

The system was then decomposed into the following functions:

- Receive Communication Information (A1) includes receiving the signal / waveform, and demodulation of the signal into an appropriate form for processing.
- Process Communication Information (A2) includes the determination of the type of communication (I, II, or clear), decryption of the communication if needed, processing of the incoming or generated communication, storage of data for later use, storage of the encryption of key material (I or II), and finally the re-encryption of the communication for later transmission.
- Generate Communication Information (A3) generates the required communication information in either data or voice communication and modulated the input for communication processing.
- Convey Information to User (A4) converts the signals processed in the systems and either displays the information or broadcasts the voice information to the user.
- Transmit Communication Information (A5) is the inverse of the receive communication in which the signal is modulated, amplified, and transmitted.
- Provide Power (A6) provides the inherent capability required to facilitate the other functions. This assumes that the system must be self-sufficient and not allocated to another system within the MERS concept.

3. Physical Architecture

The Physical Architecture allocates the functions from the Functional Architecture to sub-systems which are further defined as actual hardware or software components. This allocation also defines what the sub-system is required to perform to make the system operationally effective. Most functions have a one-for-one traceability to the physical architecture with the exception of the receiver / transmitter sub-system (Figure 13).

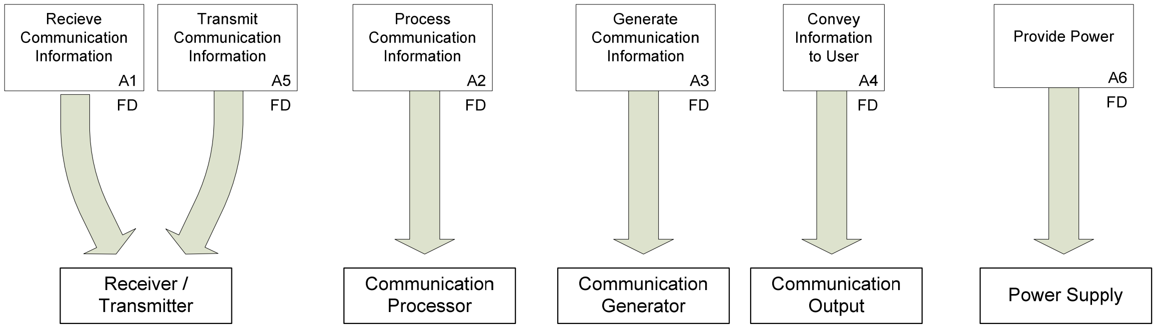


Figure 13: Traceability from Function to Sub-system

The Physical Architecture (Figure 14) was derived from the functional trace performed above and can be used as simple program Work Breakdown Structure (WBS). The elements are generic descriptions of the key sub-systems which will eventually be decomposed to hardware, software, and human components later during system design.

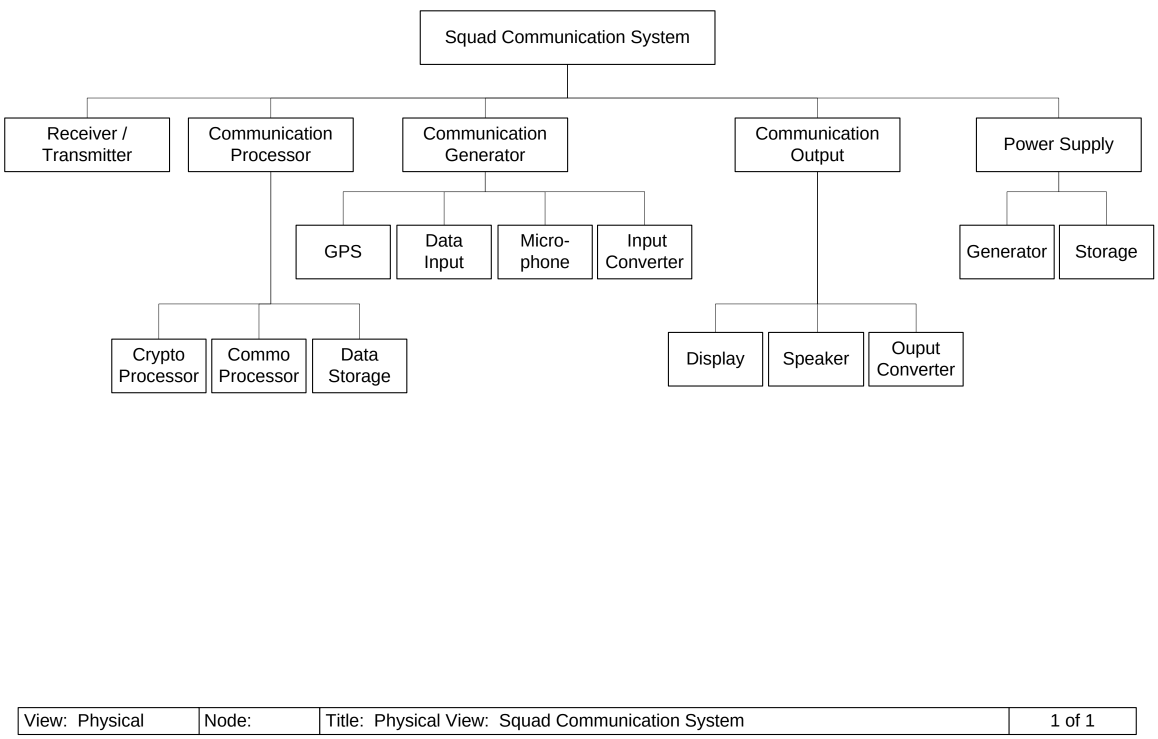


Figure 14: Physical Architecture

The Functional Architecture is related to both the Objective Hierarchy and Physical Architecture and traceable to both products (See section IIIA2 above)

B VALUE SYSTEM DESIGN

In order to determine the evaluation measures important to the Marine Squad Leader, the team met with members of the Marine Expeditionary Rifle Squad (MERS) program office staff. The group created a list of attributes for the new system as depicted in Table 1: System Attributes

Table 1: System Attributes

Weight	Volume	Capability	Ease of use
Battery duration/life	Durability	Voice	Text/data/images
Anti-spoof	Redundancy	Security	Bandwidth
Reliability	Range (miles)	Easy to learn	Easy to remember
Size/transportable	Status Indicators	Commonality	Modularity
Multiple environments	Interoperability	Adaptable power source	

1. Objective Hierarchy

The development of effective value criteria, as expressed in an Objectives Hierarchy, is critical to successful project development. The Objective Hierarchy is intended to ensure that the correct objectives and measures of effectiveness have been identified so that the correct system is designed and successfully validated against the needs, expectations, and constraints of the ultimate end user, the USMC.

2. Value System Modeling

Using existing documents and discussions with key stakeholders, USMC subject matter experts, and other research data, previously identified in this report, the Team has defined the Effective Need Statement and functional decomposition of the top level functions to develop the Objective System Hierarchy shown in Figure 16 through 19.

The Objective Hierarchy provides a top-down approach starting with the Functional and Non-Functional Attributes derived from the Effective Needs Statement, (described in Section IIB3), and subsequently flowing down into two major categories namely Functional and Objective Hierarchy (Figure 16 and Figure 17) and Non-Functional Attributes and Objectives (Figure 18 and

Figure 19). Specific measures of effectiveness are assigned to each objective for Analysis of Alternatives (AoA) and verification purposes.

Selection of the measures of effectiveness is based on the requirements derived from the available documentation as they apply to the system along with other requirements discovered by the Team as part of Needs Analysis. For example, stakeholder analysis has identified the ability to communicate to both higher and lower echelons via one radio as one of the most important objectives driving the need for a communications system. Therefore weight and volume are typical measures of effectiveness that are used in the decision making process. Attribute N5, chosen to ensure usability and human factors uses weight, volume, maximum total workload and operational use as the measures of effectiveness used to evaluate this attribute.

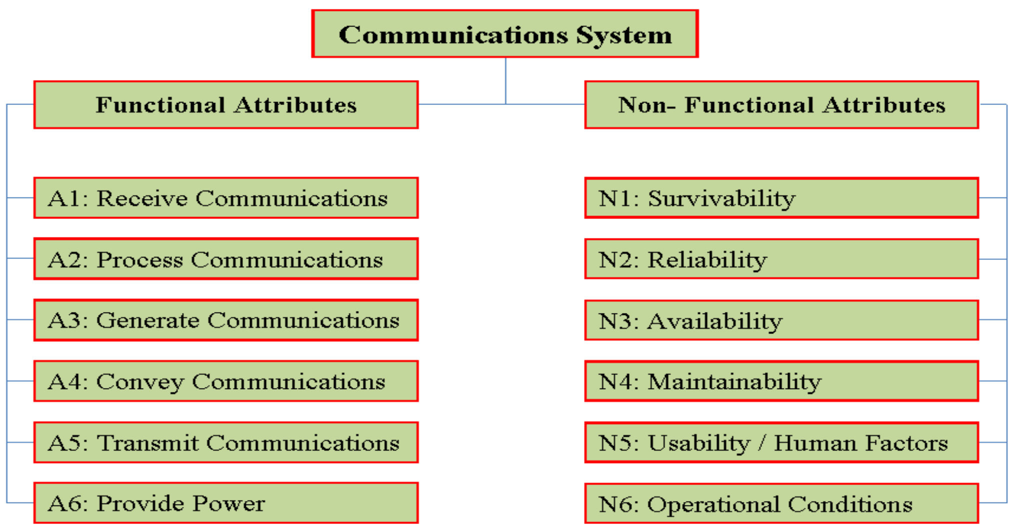
The system must be operational and maintainable in all types of climate and terrain where Marines deploy or may deploy. Therefore maximum and minimum temperature, quantity of rain, snow, ice, and wind velocity are important measures of effectiveness.

Attribute N6 references military standards that state the environmental requirements and these requirements must be met by each alternative in order to be considered in this evaluation in order to ensure operation in all environments.

Duration of power and percentage of incoming and outgoing messages processed are some of the other measures of effectiveness used in the decision making process.

Each measure of effectiveness is depicted in a box at the end of its corresponding bottom level function/objective. The measures of effectiveness denoted with an asterisk are used to evaluate the different alternatives discussed in section IIIB3 below.

The team chose the measures of effectiveness to use in the decision making process by determining what data would provide the greatest distinction between the alternatives and could be gathered from the modeling and simulation process and the research sources.



[2]

Figure 15: Functional and Non-Functional Attributes

Selection of the measures of effectiveness is based on the requirements derived from the available documentation as they apply to the system along with other requirements discovered by the Team as part of Needs Analysis.

Functions A1, A2, and A5 [Figure 16] are related to the radio(s) associated with the squad leader communications system. The stakeholder analysis identified the ability

to communicate to both higher and lower echelons via one radio as one of the most important objectives driving the need for a communications system. Therefore goals and MOEs associated with the radio system were focused on ensuring the radio(s) worked as multiband radios with proper encryption and little to no errors associated with the objective single radio development.

Function A6 [Figure 16] addressed another identified area of great importance based on analysis and stakeholders desire for lighter and more efficient power generation capability. This was evaluated by collecting raw data and specifications on available batteries.

Functions A3 and A4 [Figure 17] are related to the information processing capability associated with the integrated communications system. The goals and MOEs associated with these objectives are to ensure the user interface and input/output devices reduce human and system error. Through interviews and analysis of after action comments it was quite apparent that the squad leader's primary focus cannot be taken away from his tactical tasks to deal with inaccurate or erroneous information being conveyed to him. He must be able to trust the information and data being offered to him as factual and reliable or the system becomes a hindrance vice an asset.

Attribute N5 [Figure 18] deals with human factors; form factor, weight ease of use, user interface simple configuration and operation, etc. If the system's benefits do not satisfy the operator, then the system will be characterized as operationally ineffective and will not be used during operations. Part of this attribute was evaluated with raw data, a cognitive model and evaluated by the team via a Likert scale.

Attributes N2, N3, and N4 [

Figure 19] are related to the system's reliability, availability and maintainability. Through the needs analysis, interviews and stakeholder analysis it was determined that the squad leaders will only take equipment to the field that they have full reliance on and can be almost certain that it will not break or become ineffective during a mission. The packed out load for a Marine is near 95 pounds already and near unbearable by most. Any additional weight will only be acceptable if the system brings added utility with minimal impact to the operators.

Attributes N1 and N6 [

Figure 19] are directly related to a physical and electronically hostile environments. The system must survive enemy electronic counter-measures as well as the rigors associated with operating in a combat zone that promises anything but a “walk in the park.” Attribute N6 references MIL-STD 810, a military standard that defines the environmental requirements that must be met by each alternative in order to be considered in this evaluation, thus these measures were colored Blue to represent that without meeting these requirements, then the alternative was discarded.

Attributes A1, A5 and N6 are considered to be the entry criteria attributes. All alternatives had to meet these in order to be considered and thus could have been used in the feasibility screening process. However, the team determined that these attributes are unique to each system being considered and thus could be considered and used as differentiating MOEs.

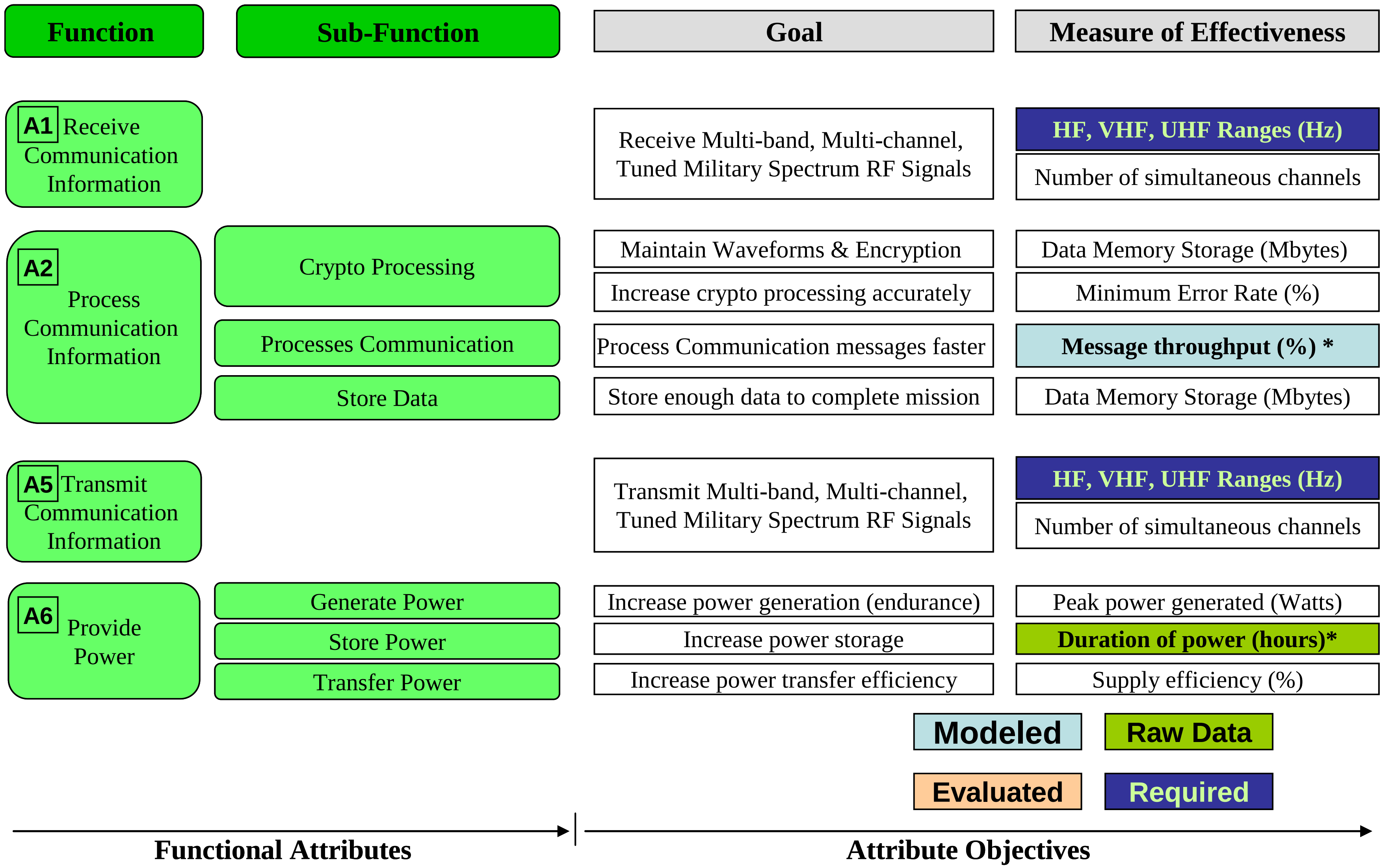


Figure 16: Functional Attributes and Objectives

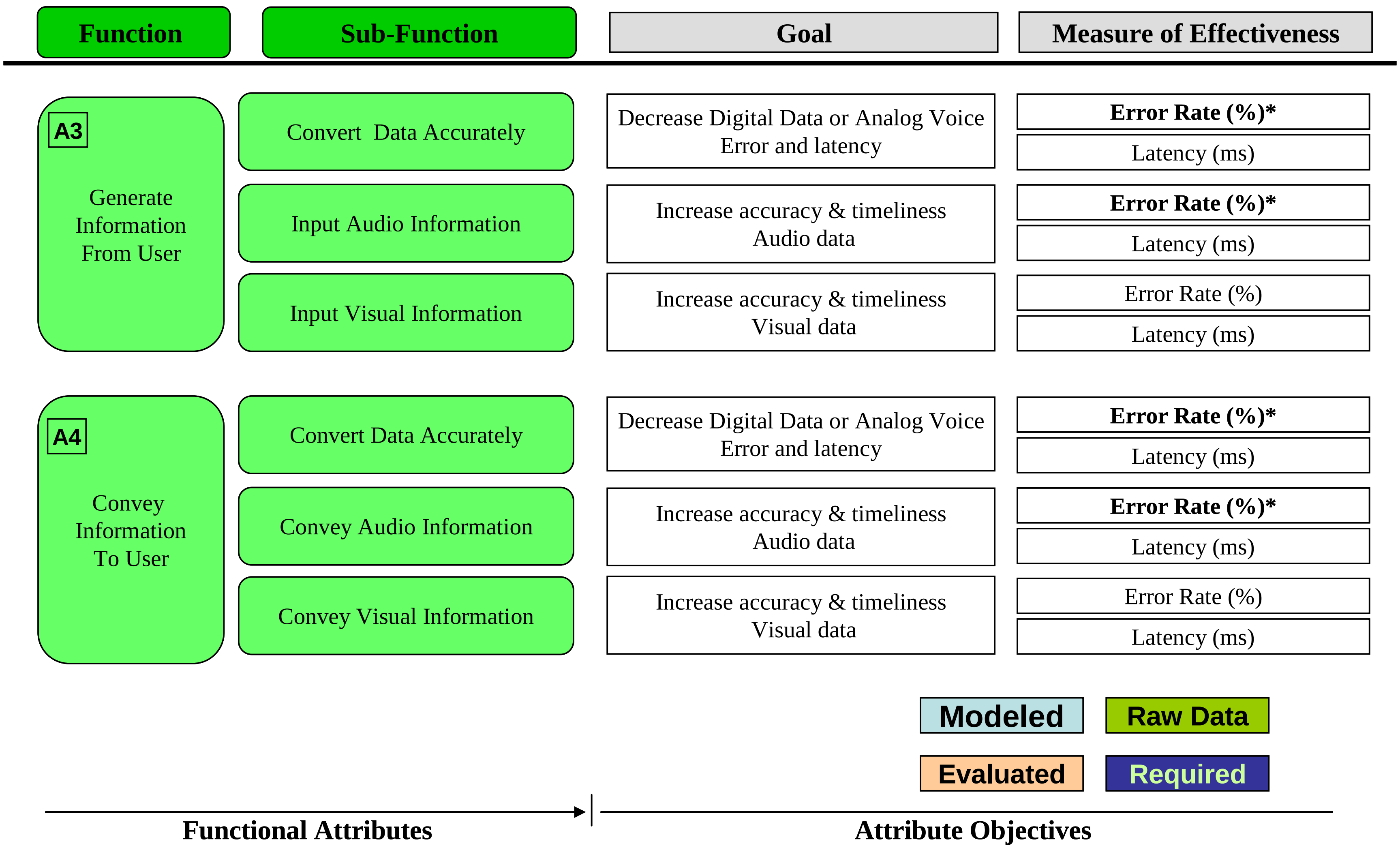


Figure 17: Functional Attributes and Objectives (cont)

Attribute	Description	Goal	Measure of Effectiveness
N5 Ensure Usability & Human Factors	Minimize Weight	Reduce weight from the status quo	**Weight Reduction (lbs/ozs)***
	Physical Size for handheld use	Reduce size from the status quo	Volume Reduction (in^3)
	Comprehensive Visual Data	Maximize Display & Character Size in all conditions	Screen Dimensions (in)
			Readability (Likert Scale 1-7)
	Comprehensive Audio Data	Maximize Quality Clarity in all conditions	Tone Frequency (Hz))
			Gain (dB)
	Ability & Complexity to Consume Analog & Digital Data	Minimize Workload of operator	**Workload assessment rating (1-7)***
	Ability & Complexity to Create Analog & Digital Data	Easy to Configure, Program, & Enter Data Maximized Accuracy w/ Minimum effort	Avg time to enter data (s)
			Avg time to enter crypto (s)
			Operational Use (Likert Scale 1-7)*

Modeled **Raw Data**

Evaluated **Required**

Non - Functional Attributes → | **Attribute Objectives**

Figure 18: Non-Functional Attributes and Objectives

Attribute	Description	Goal	Measure of Effectiveness
N1 Ensure Survivability	EMP/EMI Resistant	Maintain Operation in an EMI environment	Increased SNR (dB) Gain
	Jamming Resistant	Reduce effects of jamming	Increased SNR (dB) Gain
N2 Ensure Reliability	Overall Reliability of Communications System	Increase the mean time between failure	**Mean Time Between Failure (%)***
N3 Ensure Availability	Overall Availability of Communications System	Increase Operational Usage / Total Time In all conditions	Operational Availability (%) In all conditions
N4 Ensure Maintainability	Overall Maintainability of Communications System	Reduce MTTR	MTTR (Hrs)

Modeled Raw Data

Evaluated Required

Non - Functional Attributes → | **Attribute Objectives** →

Figure 19: Non-Functional Attributes and Objectives (cont)

3. Evaluation Measures and Weighting

After finalizing the Functional Hierarchy for the system, the team focused on defining the key evaluation measures and weights to be used for the Decision Matrix. The weights are based on the stakeholders' inputs that were discussed earlier in this report.

The values of the weights were based on the subjective assessment by the team of the stakeholder preferences. The team evaluated over forty measures of effectiveness that could be used as the foundation for the weighting factors. After a thorough review of the Needs Analysis and the stakeholder inputs it was apparent that the factors that had the greatest effect were associated with employability. Weight was selected as the best factor to encompass the key physical attributes of the system (size, weight, and transportability). Duration of Power was determined as the best factor to encompass power generation due to the fact that less duration requires additional spare power to be carried. The other factors associated with the squad leader's interface to and reliance on an integrated system that would make the system worth adding to the combat load due to the increased capability offered to the squad leader. The agreed upon weighting for the seven evaluation measures are identified in Table 2 below.

Table 2: Weighting Factors

Evaluation Measures	Metric	Weighting factor
Weight	pounds	20
Duration of Power	hours	15
Operational use	1 though 7 scale	15
MTBF	%	15
Max Total Workload	workload units	15
Incoming msg % processed	%	10
Outgoing msg % processed	%	10
Check Sum =		100

The team used these weighting factors to evaluate the alternatives and determine the best Course of Action (COA) which is described later in the document. Physical characteristics of the radio (weight), operational characteristics of the radio (Power, Operational use, and MTBF), and cognitive characteristics of the user (max total workload, incoming message percent processed and the outgoing messages percent processed) were derived and selected as the key weighting factors in this study. While

there were other measures, the seven selected measures were based on stakeholder input and team analysis.

IV MODELING AND ANALYSIS

A ALTERNATIVES GENERATION

Prior to selecting products or solutions, a list of alternatives must be generated. Within the DoD, there are directives, and instructions that direct the SE process to utilize other means of analysis and evaluation, prior to selecting a solution. The following paragraphs describe these additional evaluations.

1. Doctrine Organization Training Materiel Leadership Personnel and Facilities (DOTMLPF)

Throughout the SEDP, it was quite apparent that a material solution would be required to achieve the desired squad leader communications and networking capabilities as outlined and described earlier in this report. The team spent a great deal of time in determining the material solutions and describing in detail how each alternative offers enhanced and evolving capability to the squad leader. All material solutions being evaluated for incorporation into military equipment must also be assessed on six non-material areas that are defined by the Defense Acquisition University as DOTLPF.

2. Non-material Alternatives (DOTLPF)

a. Doctrine

The doctrine of the Marine Corps continues to evolve and adapt. Doctrine does not currently discuss or consider distributed squad offensive operations. Nor does it consider the affects of connecting and networking forces for situational awareness and command and control below the battalion formations. As the squad leader communications and decision making tools evolve, so must the doctrine evolve to adequately address the potential battlefield enhancements that a networked force can bring to bear in "networked operations."

b. Organization

The current organizational construct addresses the squad as the smallest combat organization. The squad is currently organized as "trigger pullers" with a "point me in the right direction and let me go do the mission" perspective. With added C2 and SA capabilities it will be necessary to add or accommodate for advanced skill sets in line with the enhanced information technologies (IT). The squad will continue to be organized and tasked as the "trigger pullers" of the

Marine Corps but an organizational assessment must be conducted within the current structure of the infantry battalions to determine if the current company-platoon-squad-fire team organizations continue to be necessary.

c. Training

As the IT capability enhancements and the increased skill sets are addressed it is imperative to assess current squad level training. To the extent possible, no IT enhancements should dramatically increase training requirements.

d. Leadership:

Current Marine Corps leadership may not be ready or prepared for squad level distributed operations. These operations will have to be considered and properly reinforced as capabilities are added and squad connectivity changes tactics and the "information domain" within the battlefield.

e. Personnel

Additional personnel may have to be added to the current squad table of organization. Further assessment must be considered as the IT enhancements become realized and are employed effectively at this level of distributed operations.

f. Facilities

A full assessment will be required to determine amount of added gear and level of storage security required for garrison and when embarked on amphibious shipping.

3. Material Alternatives Developed

The team explored existing, new and future alternatives in a variety of combinations in order to evaluate the capabilities of existing communications systems and compare these to the functional needs of the Marine Squad. The team evaluated the different technical, logistical, and fiscal considerations using systems engineering principles and analysis.

A '*Zwicky's Morphological Box*' was used as a technique to develop possible system alternatives. This approach encourages brainstorming at the sub-system level and

the subsequent combination of the brainstormed ideas in untried combinations as a way to produce new approaches to be vetted in feasibility screening phase of the SEDP.

The first step in Zwicky's process is the definition of system elements. These elements correspond to the functions described in our Value Model in Figure 20. These elements were defined as:

- Receive/Transmit
- Communication Processor
- Communication Generator
- Convey Information to User
- Power Supply

The SE team then combined various combinations of functions to establish alternatives. Using engineering judgment, the SE team eliminated the impossible solutions while preserving both common and unusual combinations for comparison in feasibility screening.

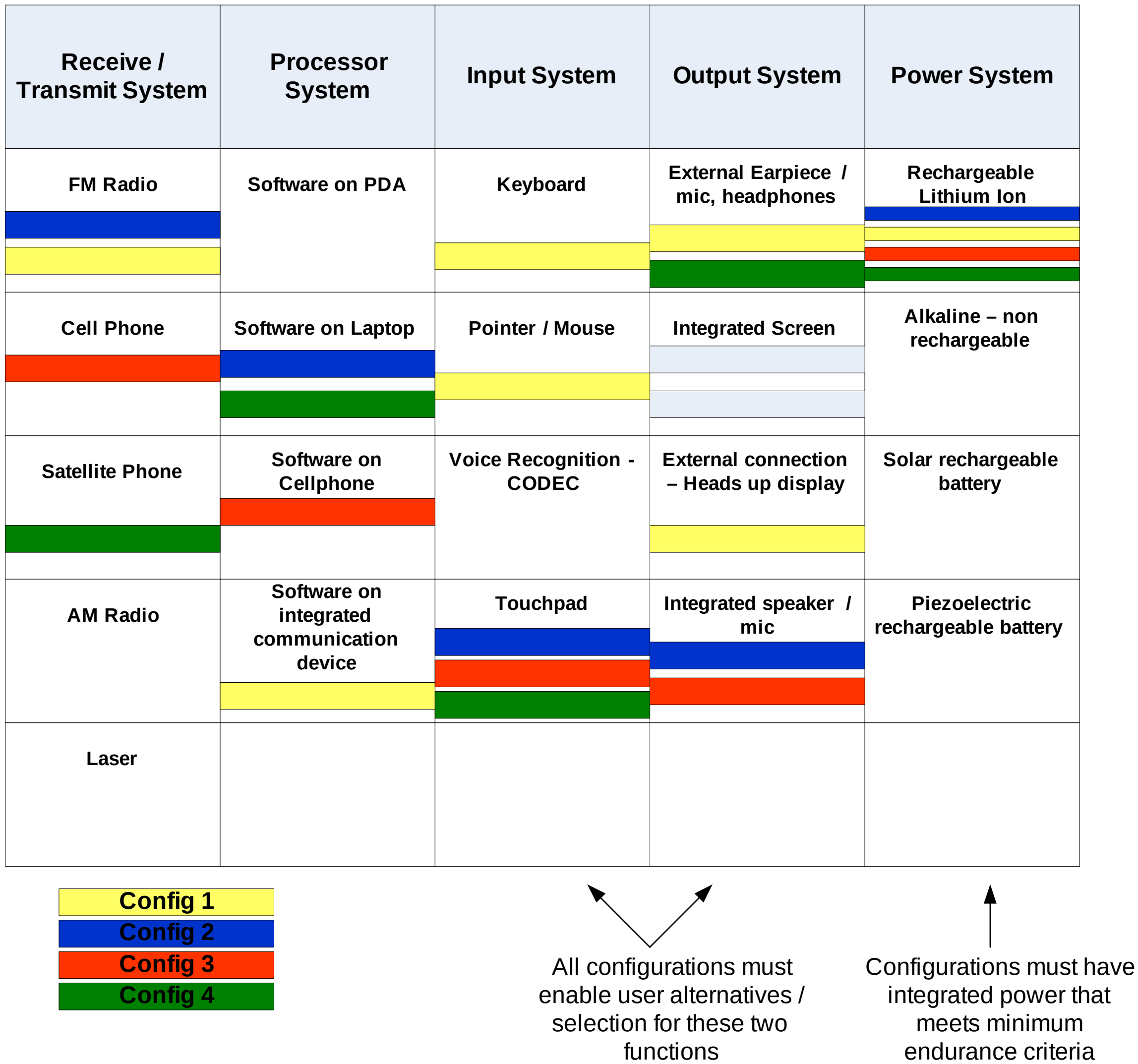


Figure 20: Morphological Box

4. Feasibility Screening

The goal of the Systems Engineering design process is to come up with a single solution that will best meet the needs of the Marine Corps Rifle Squad Leader. Team Marine executed a detailed analysis of the required functionality of the squad communication system based on utilizing handheld radio unit(s). In addition, scenarios were drawn up discussing how the system will be used in a real-time operational environment. The SE team took all the requirements and generated a list of material alternatives / solutions. Often the alternatives generated may not be technologically or financially viable. These solutions were put through a feasibility screening process to help the team move towards indentifying a single hand-held radio solution that will best fulfill the effective needs statement outlined in section IIB3 above.

Feasibility screening is an iterative process and is designed to give Systems Engineers a way to methodically eliminate solutions after the alternatives generation brainstorming phase that are determined to be clearly infeasible. In most cases, infeasibility is determined when applying the alternatives against a list of system and program constraints. These constraints may be performance-based, such as the radios need to be able to send/receive both voice and data. Oftentimes, depending on the stage of the program, a team may apply financial or economic constraints on the alternatives, in order to eliminate systems that may be just too costly to acquire.

The nine constraints that Team Marine identified to be relevant are as follows:

1. The overall system weight shall be lighter when compared to "status quo" configuration
2. The system shall be capable of transmitting and receiving Type I and Type II encrypted messages – (2 channels minimum)
3. The system shall be capable of supporting world-wide spectrum supportability – (must support a variety of DoD frequency ranges)
4. The system shall have the capability to support enhanced data capability including digital data and streaming video – (can not be voice only)
5. The system shall have the capability to recharge power sources during mission operations – (charging must occur while in operation)

6. The system shall be capable of gracefully entering and exiting a tactical ad-hoc network
7. The system shall be configurable by users below Squad Leader
8. The system shall operate independent of commercial telecommunication infrastructure
9. Range for both Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) shall be at least 3 km

The team applied the Feasibility Screening Matrix Table 3 below, which identifies specific constraints to the alternatives, to the multiple configurations identified in Figure 20. This activity reduced the total number of alternatives identified above to those practical alternatives that need further investigation and analysis.

Table 3: Feasibility Screening Matrix

	FM Radio Configuration 1	FM Radio Configuration 2	Cell Phone Configuration 3	Satellite Phone Configuration 4
Operate in Military Spectrum Bands				
National Security Agency (NSA) certified or certifiable				
Joint Integrated Test Center (JITC) certified or certifiable				
JTRS SCA 2.2 compliant				
Requires no Satellite Communication (SATCOM)				
Independent of commercial telecom infrastructure				
Backwards compatible with existing systems until FOC				

Configurations identified above in the Morphological Box in Figure 20 are further subjected to operational and support criteria. A brief description of operational and support issues that each alternative was subjected to follows.

a. ***Operational Issues:***

To best suit the user requirements, the following operational issues must be satisfied by each alternative in consideration.

- The system shall operate in accordance to standards established by Military Spectrum Specification, MIL-STD 449D
- The system shall meet all Operational Environmental specifications identified in MIL-STD-810F
- The system shall be certifiable by assessment standards as established by National Security Agency (NSA)
- The system shall be certifiable by assessment standards as established by the Joint Interoperability Test Command (JITC)
- The system shall be compliant to current Software Communication Architecture (SCA) standards
- The system shall be capable of sustaining internal power requirements for missions lasting no less than 8 hours
- The system shall operate independently of external power

b. ***Support Issues:***

To best suite the user requirements in the field, the following Support issues must be satisfied by each alternative in consideration.

- The system shall be inter-operable with existing and legacy waveforms
- The system shall be inter-operable with existing fielded communications systems
- The system shall be hardware and software upgradeable without major re-engineering
- The system shall maximize use of existing DoD, and USMC logistical support elements, including software licensing, batteries, computers, etc.

- The system shall be ergonomically designed to fit and integrate with existing soldier gear

B RECOMMENDED ALTERNATIVES

This section describes the four (4) selected alternatives based on the completion of the Feasibility Screening process above. Configurations #2 and #4 in Table 3 provided the team direction to look at specific alternatives. The operational and support issues were used to further refine the alternatives prior to any further analysis. Each alternative below has five physical sub-systems as seen in Figure 21. These five physical sub-systems are required to support the functional requirements in order achieve the desired operational capabilities of the Squad Leader. The five primary sub-systems are:

- User Input System, (microphone, touch pads, keyboards, etc)
- Output System, (speakers, headsets, LCD display)
- Processor System, (Computer Processing Unit (CPU) provides system configuration, position location information, executes software programs and executes encryption functions as required)
- Receiver / Transmitter (Rx/Tx) System, (Radio Frequency (RF) spectrum management, modulation and amplification of RF signals)
- Power System, (batteries or other electrical power supply)

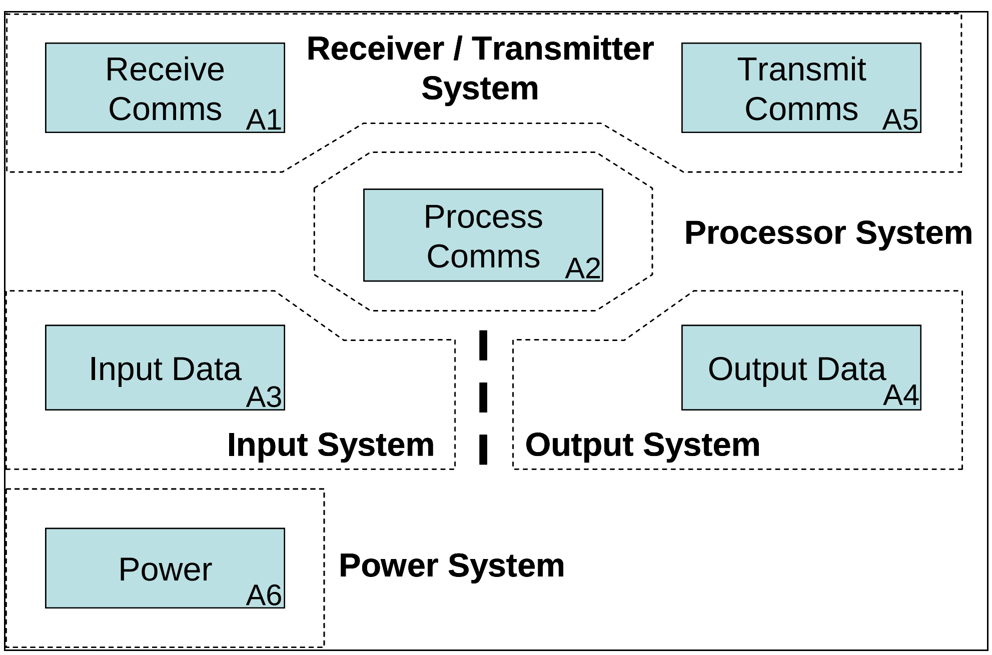


Figure 21: Key Physical Components of Alternatives

1. Primitive Alternative: (Status Quo)

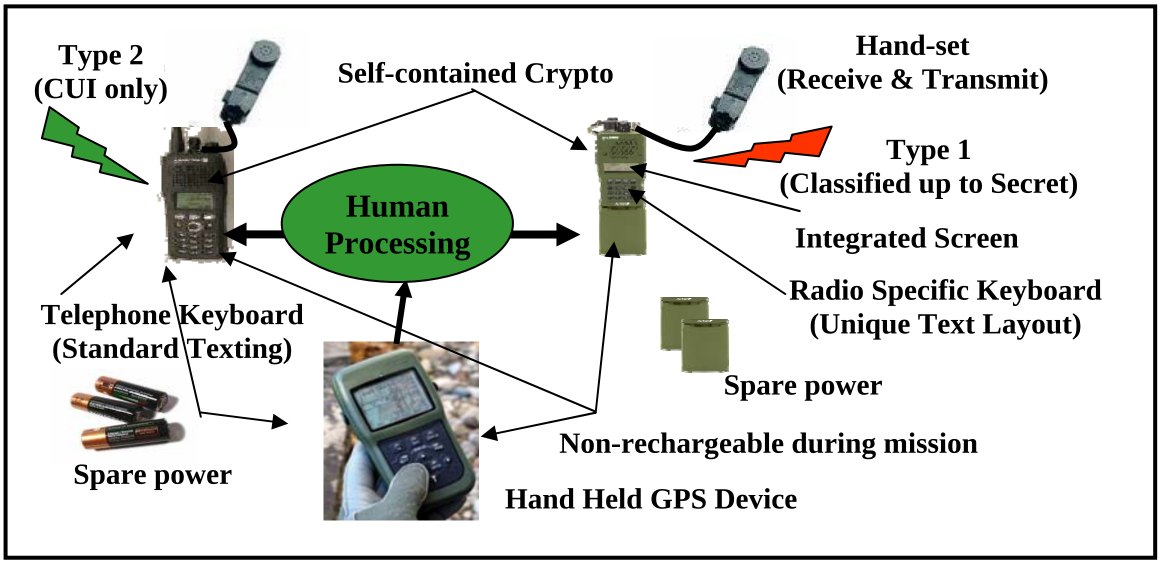


Figure 22: Primitive Alternative

The primitive alternative is the currently fielded solution being employed by Marine squad leaders in training areas, school houses and in ongoing combat operations. Figure 22 describes the alternative by the specific components. This alternative is comprised of multiple items that were purchased and fielded by separate Programs of Record managed by Marine Corps Systems Command (MCSC). These items were not bought as an integrated system and are not fundamentally interoperable or meant to be employed together. However, the squad leaders have learned how to employ these items in an integrated capable system to meet minimum functionality and capability.

Input System

The input devices are comprised of hand-sets or internal microphones for voice input communications. The operator must use a simple switch to select which radio device they desire to communicate on. There is no data capability currently associated with this alternative. External and disconnected from the radio(s) is a handheld GPS unit that provides the squad leader with current position and any pre-programmed routes or way-points associated with anticipated and planned mission profiles. The squad leader must read the data from the GPS in order to communicate this information across the voice only circuits and must do this once on the

Type 1 AN/PRC 152 radio and again on the Type 2 IISR (AN/PRC-153) radio.

Processor System / CPU

There is no data processing capability associated with this alternative. The squad leader must process all voice traffic and must generate their information as a mental image.

Power System

There are three non-interchangeable types of batteries associated with this alternative. The IISR (AN/PRC-153) uses commercially procured A-cell batteries. The AN/PRC-152 uses military procured chargeable and one time use BA-5590s batteries. The GPS unit uses an internally rechargeable battery which has an option of using commercially procured C-cell batteries.

Rx/Tx System

There are two radios associated with this alternative that are not interoperable and do not share or use a common transmission spectrum. The IISR (AN/PRC-153) is a line-of-site radio that provides preprogrammed channels associated with Radio Nets for team and leader voice circuits. The IISR (AN/PRC-153) has a short transmission range of less than 3 kilometers with degraded capability in heavy vegetation and urban structures. The AN/PRC-152 has a longer transmission range that extends to 10 kilometers but is also line-of-site dependent and also encounters degraded capability when employed in heavy vegetation and urban structures.

Output System

There is only one headset or handset with a speaker or ear-piece for the operator to listen with. The operator listens to both radios simultaneously. Each radio has a small LCD display which also provides information to the user. There is currently no visible texting or video capability on either radio.

2. Current Alternative:

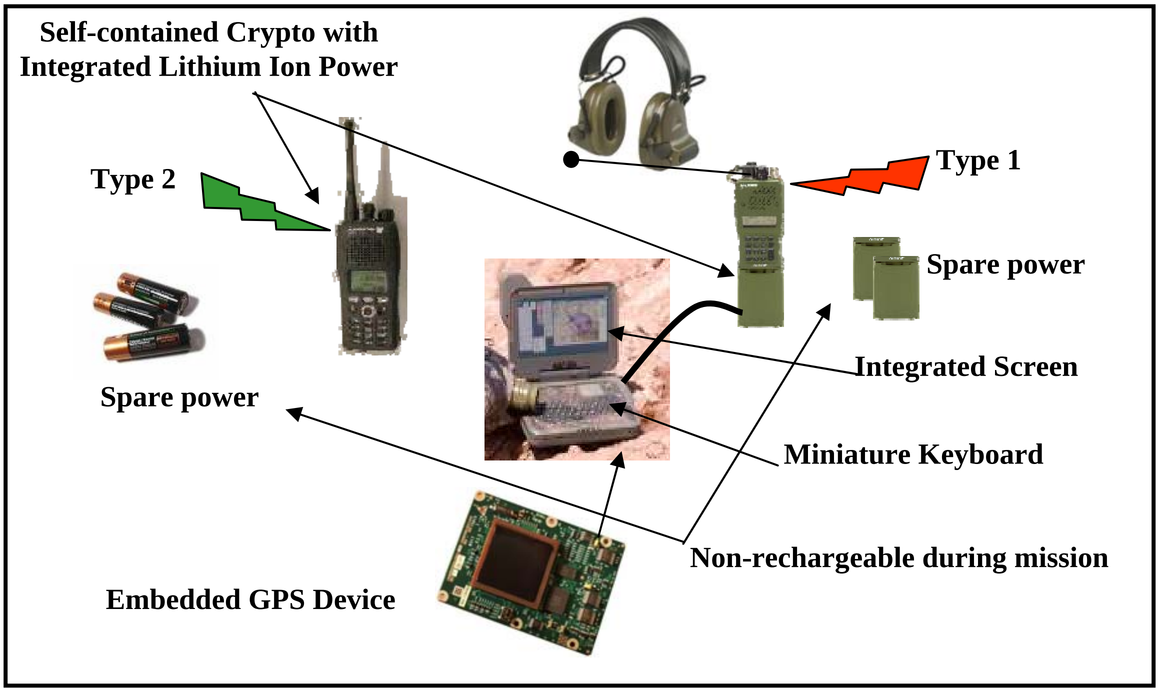


Figure 23: Current Alternative

This alternative is identical to the Primitive Alternative with the following exception; an integrated, ruggedized laptop that has an embedded military GPS receiver. This enhancement is currently being fielded and employed by a few select U.S. Marine squad leaders in training areas, and school houses. The Current Alternative (Figure 23) is comprised of many of the same items that were purchased and fielded by Marine Corps Systems Command (MCSC) for the Primitive Alternative. Again these items were not bought as an integrated system and are not fundamentally interoperable; however, the squad leaders have learned to employ these items in the field to meet operational needs.

Input System

The input devices are comprised of hand-sets or internal microphones for voice input communications, and a ruggedized laptop to input and receive data communications. Integrated into the laptop is an embedded GPS unit that provides the squad leader with current position and any pre-programmed routes or way-points associated with anticipated and planned mission profiles.

Processor System / CPU

The ruggedized laptop provides minimal computing capability to convey and display unit level C2/SA. The laptop is configured with military and commercial software offering limited data capability to the squad leader.

Power System

There are three non-interchangeable types of batteries associated with this alternative. The IISR (AN/PRC-153) uses commercially procured A-cell batteries. The AN/PRC-152 uses military procured chargeable and one time use BA-5590s. The laptop unit uses an internally rechargeable battery with option of using externally generated DC power.

Rx/Tx System

There are two radios associated with this alternative that are not interoperable and do not share or use a common transmission spectrum. The IISR (AN/PRC-153) is a line-of-site radio that provides preprogrammed channels associated with Radio Nets for team and leader voice circuits. The IISR (AN/PRC-153) has a short transmission range of less than 3 kilometers with degraded capability in heavy vegetation and urban structures. The AN/PRC-152 has a longer transmission range that extends to 10 kilometers but is line-of-site dependent and also encounters degraded capability when employed in heavy vegetation and urban structures.

Output System

There is a cable required to connect the laptop to the AN/PRC-152. This cable is made specifically for this radio and is proprietary to this employment option.

3. Advanced Alternative:

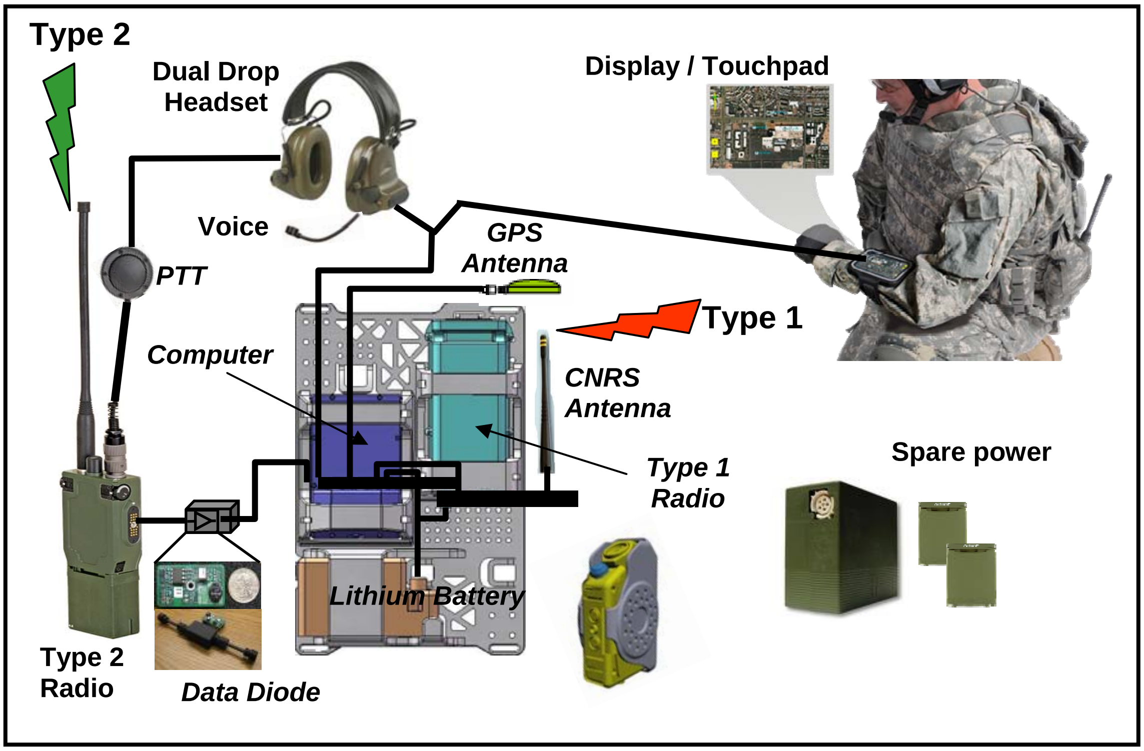


Figure 24: Advanced Alternative

This alternative is a first attempt at providing the squad leader with a fully integrated system comprised of wearable and hand-held sub-systems. This design is being evaluated by PM Soldier for the Ground Soldier Ensemble (GSE). It offers user tailorable allowing for each squad leader or unit to determine best mix of capability. The Advanced Alternative (Figure 24) is currently being evaluated by the Army and select Marine Corps units for consideration. Previous prototype designs of this alternative have been employed by soldiers in operations in Iraq and are currently being employed in both Iraq and Afghanistan.

<u>Input System</u>

The input devices are comprised of hand-sets or internal microphones for voice input communications, and user specified data input devices. Several alternative data input devices are being evaluated to include "gameboy" controllers, touch-screens, hand-held mouse assembly units, and wearable keypads. Integrated into the system is an embedded GPS unit that provides the squad leader with current position and any pre-

programmed routes or way-points associated with anticipated and planned mission profiles.

Processor System / CPU

The wearable computer provides advanced computing capability to convey and display unit level C2/SA. It is configured with military and commercial software offering enhanced data capability to the squad leader.

Power System

There are two non-interchangeable types of batteries associated with this alternative. The Rifleman Radio (RR) uses military procured chargeable and one time use BA-5590s. The wearable backpack system uses an internally rechargeable battery with option of using externally generated DC power.

Rx/Tx System

There are two radios associated with this alternative that are interoperable and do not share or use a common transmission spectrum. Due to the two classification levels, the RR via a data-diode injects individual Position Location Information (PLI) into the fully operable data processing unit worn by the squad leader. The radios are line-of-site radios that provide preprogrammed channels associated with Radio Nets for team and leader voice and data circuits. They are line-of-site dependent and are effective for ranges of 10-15 kilometers and also encounter degraded capability when employed in heavy vegetation and urban structures. The radios provided through the Joint Tactical Radio System (JTRS) bring enhanced capability by providing meshing and ad-hoc networking.

Output System

The cable assembly is integrated into the wearable system with the ability to use external cables for user specific employment options.

4. Future Alternative:

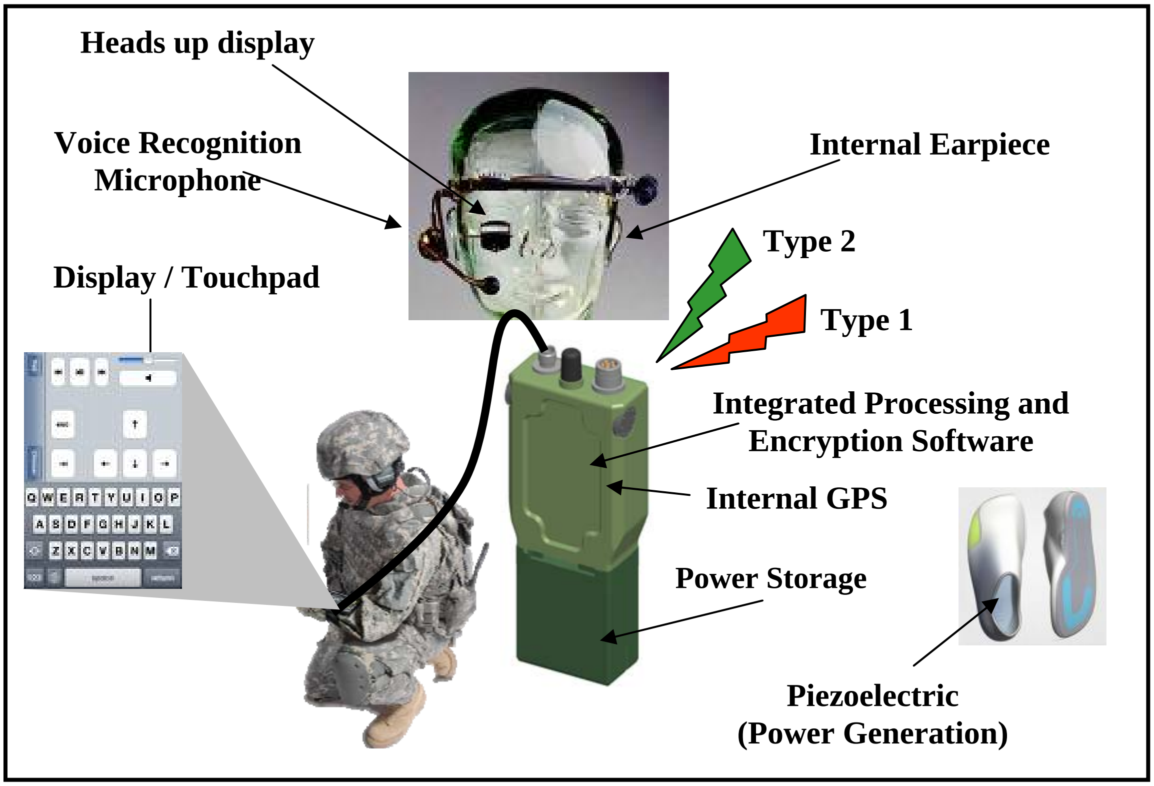


Figure 25: Future Alternative

This alternative is only a concept at this point as only a few components are commercially available, while many others are currently under Research and Development today. The Future Alternative (Figure 25) represents a fully integrated system, with a complete evaluation of human factors.

<u>Input System</u>

The input devices should be tailorable and provide user input associated with "I-touch" like capability.

<u>Processor System / CPU</u>

The wearable computer should provide advanced computing capability to convey and display unit level C2/SA. It is configured with military and commercial software offering enhanced data capability to the squad leader.

Power System

The power supply should seek alternative power generation alternatives – one example is the piezoelectric powered insoles pictured above.

Rx/Tx System

The radio provided through the Joint Tactical Radio System (JTRS) or other programs must provide integrated, multi-level security into a single device with enhanced capability by providing meshing and ad-hoc networking.

Output System

The output system must be compatible with night vision displays or goggles. This design should seek to minimize cables and use wireless alternative options to “tie” the devices together – much like Bluetooth does for headsets and cell phones.

C MODELING AND SIMULATION

1. Tools and Approach

The Squad Communication System model was developed using Arena 10.0 student version. Arena is a modeling and simulation tool produced by Rockwell Automation to provide the user with alternative and interchangeable templates of graphical simulation modeling and analysis modules that can be graphically combined to mathematically model and simulate systems for detailed analysis of the system. (Kelton, Sadowski, Sturrock, 2007). The model represents a Marine Corps Squad Leader’s ability to receive, generate, and process communication messages. The model measures the workload associated within a typical squad employment scenario and measures the ability of a of the squad leader to communicate with higher headquarters and the squad fire teams. The Squad Communication model is a queuing model to mimic workload capacity of a Marine Corps Squad Leader.

a. Workload Methodology

The workload methodology for modeling human performance is based on the multiple resource theory for discrete events originally developed by Wickens (1984).

Wickens described work load as total demand placed on human as he/she performs a task (as cited by Keller, 2002). Workload could thus be described as the total demand placed on the Squad Leader as he/she performs a task. In Multiple Resource Theory, workload is not just the result of one central processing resource but the use of several processing resources or workload channels. The multiple resources are described as visual, auditory, cognitive and psychomotor. Rating scales for each of these resources were developed to describe the workload required to do generic tasks or anchoring statements. The rating scales in Figure 2 were originally developed based on work by McCrasken & Aldrich (1984) and Bierbaum, Sxabo & Aldrich (1987). However the rating scales updated in 2000 by the Army Research Laboratory (Mitchell, D.K. 2000) and used in the task analysis for performing the system communication functions.

Table 4: Simulation Descriptors and Scale Values

Descriptors	Scale Value
Visually	
Visually register or detect (detect occurrence of image)	3.0
Visually inspect or check (discrete inspection or static condition)	3.0
Visually locate or align (selective orientation)	4.0
Visually track or follow (maintain orientation)	4.4
Visually discriminate (detect visual differences)	5.0
Visually read (symbol)	5.0
Visually scan or search monitor (continuous or serial inspection, multiple conditions)	6.0
Auditory	
Detect or register sound (detect occurrence of sound)	1.0
Orient to sound (general orientation or attention)	2.0
Orient to sound (selective orientation or attention)	4.2
Verify auditory feedback (detect occurrence of anticipated sound)	4.3
Interpret semantic content (speech) simple (1 to 2 words) complex sentences	3.0
Interpret semantic content (speech) complex sentences	6.0
Discriminate sound characteristics (detect auditory difference)	6.6
Interpret sound patterns (pulse rates, etc)	7.0
Cognitive	
Automatic (simple association)	1.0
Alternative selection	1.2
Sign or Signal recognition	3.7
Evaluation or judgment (consider single aspect)	4.6
Rehearsal	5.0
Encoding or decoding, recall	5.3
Evaluation or judgment	6.8
Estimation, calculation, conversion	6.8
Psychomotor	
Speech	
Speech simple (1 to 2 words)	2.0
Complex (sentence)	4.0
Motor	
Discrete actuation (button, toggle, trigger)	2.2
Continuous adjustive (flight control, sensor control)	2.6
Manipulative	4.6
Discrete adjustment (rotary, vertical thumb wheel, lever position)	5.5
Symbolic production (writing)	6.5
Serial discrete manipulation (keyboard entries)	7.0

b. Communication Messages Task Analysis

The functions were taken directly from the Functional Analysis and further decomposed into specific human tasks for operating the four alternatives defined earlier in the system engineering methodology. The generic tasks associated with each function were further defined from the alternatives and given a scale value. This task analysis and assignment of value is limited in scope for this project and has evolved as a mental

exercise in performing the tasks. Further analysis should include alternative mock-ups, testing with actual users, and completed surveys to better understand the intricacies of the alternatives. This conceptual analysis will help to determine qualitative differences in levels of workload required to send and receive communication messages. The limited scope task analysis is referenced below:

Receive Communication Information:

1. No Human tasks for any alternative

Process Automated GPS:*

1. Toggle GPS buttons Read GPS (Voice only)
2. Read GPS data (Voice only)
3. Evaluate GPS data (Voice only)

Note: * Data – No Human tasks for any alternative

Process Communication Information: – Send

1. Physically change radios (if two radio solutions are used)
2. Gather information to be sent: Recall voice information if transferred from radio or retrieve stored data
3. Verbalize information into hand microphone -or- voice recognition device -or- input via a keyboard

Process Communication Information: – Receive:

1. No Human tasks for any alternative

Transmit Communication Information: – Send

1. Toggle send key -or- push send key -or- verbally send via voice recognition device.

Convey Information to User

1. Physically move handset to ear -or- open screen -or- move screen into view.
2. Listen to message or read message
3. Write down required information (voice only)
4. Evaluate information

c. Simulation Model Part Descriptions

Overall Simulation Process: The Arena model will model the communications process using discrete events, taking a message through the entire communications process over time steps and measuring Squad Leader workload. The model will process receiving or sending message as a delay, release, and by assigning a workload attribute process. These parameters will be established based on the individual solutions in the system alternatives.

Entity Generators: Each message required for the simulation for both generated and received messages is controlled by a entity generator. Each message generator introduces a communication message (entity) to the squad leader in order to process a receive message or generate an outgoing message. This entity will have attributes that describe the message and be used in the processing sub-models within the overall model

Entities Attributes: An attribute is a common characteristic of all the entities, but specific values can differ from the other entities. (Kelton, Sadowski & Sturrock, 2007). Each message has two levels of attributes 1) Message Descriptions and 2) Workload Descriptions assigned and used in the simulation.

1. Message Descriptions Attributes:

Data Message: – if 1, then this message is a data only message; if 0, this message is a voice only message

Generate Message: – if 1, then this is a message that needs to be generated; if 0, this is received message

Need GPS: – if 1, then this generated message needs GPS coordinates; if 0, this message does not need GPS coordinates.

Lines in Message: – the number of lines in the message to convey sufficient information.

Renege Time: – the max time the message is still relevant to the squad leader. Once the renege time is reached, the model will pull the entity from the queue and free up the workload resource.

2. Workload Descriptions Attributes:

Visual, Auditory, Cognitive, and Psychomotor Workload – Assigned a rating of 1 – 7 for each functional task to the system global variable as it passes through each of the alternatives. Scale values and descriptors for each of the resources are in below.

Total Workload – Total workload is sum of the resources for that specific functional task.

Global Variables: Global variables are information that reflects a characteristic of the system regardless of the types or quantity of entities in the simulation (Kelton, Sadowski & Sturrock, 2007). Variables are used in the simulation to track the workloads within the system. The workload description attributes described in the entity attributes work together to ensure the system properly disposes workload after the entity is processed. Global variables include total workload, visual workload, auditory workload, cognitive workload, psychomotor workload, and time in the system.

Queue: A queue is used to model the squad leader's ability to seize a workload resource as described by the entity workload description attributes. The queue provides the gate for the message to be sent or received without over taxing the squad leader ability to process that message (send or receive). The Communication Processing Queue will attempt to process Communication Messages (Entities) until it meets a max threshold of total workload, visual workload, auditory workload, cognitive workload, or psychomotor workload.

Resource: Once an entity reaches the queue, a resource must be pulled in order to process the message. The resource for the simulation is the max total workloads, max visual workload, max auditory workload, max cognitive workload, or max psychomotor workload. The lower the required resource, the more efficient the system alternative performed.

Table 5: Primitive Alternative Recorded Parameters

Primitive		Human Process Time (per line in message or per GPS entry)(sec) [Triangular Distribution]	Workload					Total
			Visual	Auditory	Cognitive	Psychomotor		
						Speech	Motor	
Receive Communication Information	Voice		0	0	0	0	0	0
Process Automated GPS	Voice	(10,15,20)	3	6	4.6	4	2.2	19.8
Process Commo Info_Send	Voice	(8,10,12)	0	0	5.3	4	4.6	13.9
Transmit Commo Info_Send	Voice		0	0	0	0	2.2	2.2
Process Commo Info_Receive	Voice	(8,10,12)	0	0	0	0	6.5	6.5
Convey Information to User	Voice		0	6	5.3	0	2.2	13.5

Table 6 Current Alternative Recorded Parameters

Current		Human Process Time (per line in message or per GPS entry)(sec) [Triangular Distribution]	Workload					Total
			Visual	Auditory	Cognitive	Psychomotor		
						Speech	Motor	
Receive Communication Information	Voice		0	0	0	0	0	0
	Data		0	0	0	0	0	0
Process Automated GPS	Voice	(10,15,20)	3	6	4.6	4	2.2	19.8
	Data	(3,5,8)	0	0	0	0	0	0
Process Commo Info_Send	Voice	(8,10,12)	0	0	5.3	4	4.6	13.9
	Data	(15,25,35)	0	0	1	0	7	8
Transmit Commo Info_Send	Voice		0	0	0	0	2.2	2.2
	Data		0	0	0	0	2.2	2.2
Process Commo Info_Receive	Voice	(8,10,12)	0	0	0	0	6.5	6.5
	Data	(1,2,3)	0	0	0	0	0	0
Convey Information to User	Voice		0	6	5.3	0	0	11.3
	Data		5	0	4.6	0	4.6	14.2

Table 7: Advanced Alternative Recorded Parameters

Advanced		Human Process Time (per line in message or per GPS entry)(sec) [Triangular Distribution]	Workload					Total
			Visual	Auditory	Cognitive	Psychomotor		
						Speech	Motor	
Receive Communication Information	Voice		0	0	0	0	0	0
	Data		0	0	0	0	0	0
Process Automated GPS	Voice	(10,15,20)	3	6	4.6	4	2.2	19.8
	Data	(3,5,8)	0	0	0	0	0	0
Process Commo Info_Send	Voice	(8,10,12)	0	0	5.3	4	0	9.3
	Data	(20,30,40)	3	0	1	0	2.2	6.2
Transmit Commo Info_Send	Voice		0	0	0	0	2.2	2.2
	Data		0	0	0	0	2.2	2.2
Process Commo Info_Receive	Voice	(8,10,12)	0	0	0	0	6.5	6.5
	Data	(1,2,3)	0	0	0	0	0	0
Convey Information to User	Voice		0	6	5.3	0	0	11.3
	Data		5	0	1	0	2.2	8.2

Table 8: Future Alternative Recorded Parameters

Future		Human Process Time (per line in message or per GPS entry)(sec) [Triangular Distribution]	Workload					Total
			Visual	Auditory	Cognitive	Psychomotor		
						Speech	Motor	
Receive Communication Information	Voice		0	0	0	0	0	0
	Data		0	0	0	0	0	0
Process Automated GPS	Voice	(10,15,20)	3	6	4.6	4	2.2	19.8
	Data	(3,5,8)	0	0	0	0	0	0
Process Commo Info_Send	Voice	(8,10,12)	0	0	5.3	4	0	9.3
	Data	(10,15,18)	1	0	1.2	4	0	6.2
Transmit Commo Info_Send	Voice		0	0	0	0	2.2	2.2
	Data		0	0	0	2	0	2
Process Commo Info_Receive	Voice	(8,10,12)	0	0	0	0	6.5	6.5
	Data	(1,2,3)	0	0	0	0	0	0
Convey Information to User	Voice		0	6	5.3	0	0	11.3
	Data		5	0	1	0	0	6

d. System Evaluation Simulations

As discussed previously, the purpose of the simulation was to measure workload on the Squad Leader during an operational scenario using the various alternatives. The simulation will compare the number of messages processed to the total messages sent or received through a given scenario and the amount of workload capacity required. The model will provide the following inputs in to the analysis of alternatives functions:

Table 9: Analysis of Alternative Function Simulation Output

A2 Process Communications Information		
	A22 Process Incoming Communication Messages	
		% Processed Incoming Messages
	A22 Process Outgoing Communication Messages	
		% Processed Outgoing Messages
N5 Ensure Usability & Human Factors		
	N55: Ability & Complexity to Consume Analog & Digital Data	
		Max Total Workload

e. Model Input / Output

There are three primary modules requiring inputs in order to define the system alternatives and the scenario. The first inputs are the scenario message generators. The message generators were held constant for all simulation of the alternatives. This ensured the simulation consistently sent the same number of messages in relatively same amount of time. The second inputs were the attributes of these messages. The messages varied slightly depending on the capability of the alternative to process data and voice messages. For all alternatives, except for the primitive alternative, there was a mixture of voice and data messages. For the primitive alternative, there were no data messages generated due to the lack of data capability. The input values for the scenarios generators and message attributes are located in Table 10, Table 11, and

Table 12. As the messages are being processed by the system, multiple variables and attributes were assigned to define the workload required to process a message. The workload attributes and variables are the third and final inputs to the simulation. These inputs varied with the workloads required to perform the human tasks of processing communication messages for the system alternatives. These variables and attributes are used in the queuing process of the model. The output of the simulation helped define ranking of the alternatives and the ability of the squad leader to process those messages. The processing attributes are defined in Table 5, Table 6, Table 7, and Table 8.

Input Values:

1. Messages sent and received by the squad leader include (Table 12, 13, 14)
    a. Number of lines of communications in each message
    b. Start time and frequency the message is sent or received
    c. Number of that specific type of message is sent or received.
    d. Max number of that specific type of message is sent or received during the scenario
    e. The estimated max time the message becomes irrelevant to the squad leader and is used as reneging time within the model.

2. Workload for each Functional Task (Table 7, 8, 9, 10)
    a. Human Process Time per line of the message or per GPS entry into the message.
    b. Workload for each resource and total workload for each functional task.

Workload will be measured in workload units.

Output Values:

1. # of communication messages processed
2. # of communication messages reneged
3. Average time to process messages

f. *Model* Description

The model has a main view that consists of the message generators, the message attribute assignment module, the system functional processing sub-model and the disposal module. The system functional processing model consists of data message processing sub-model, voice message process sub-model, the model queuing sub-module, and a reneging sub-module. The process data message and process voice message sub-models contain the same functions as described by the system functional architecture, but varies with workloads of processing voice or data messages.

2. Situation

The patrol is operating out of a company FOB in a third-world urban city. The FOB is well situated but has several insurgents and unfriendly personnel in the vicinity. The patrol is assessing a street corridor to determine level of hostile activity and threat associated with occupying forces. The patrol has complete conductivity with appropriate units as outlined in the operational architecture. This includes communications to the fire teams in the squad for order execution.

The scenario will only focus on the squad leader's ability to process communication in a patrol with 3 fire teams.

Patrol Scenario taken from the Operational Activity Model (OV-5) of the Marine Expeditionary Rifle Squad (MERS) Architecture. (MERS Architecture Final Practicum Project Report, June 2008). The scenario simulates a MERS Combat Operation and begins after completion of the Plan Patrol activity during the Conduct Patrol activity. The Execute Route command has been given and the maneuver squad is moving along designated route based on the predefined lat/long coordinates.

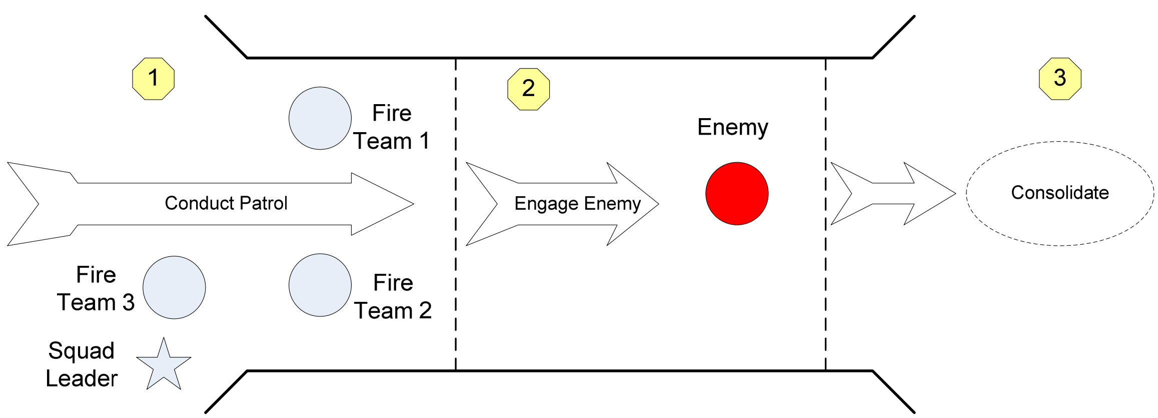


Figure 26: Simulated Scenario Model

Fire Teams will report position location information and situation updates throughout the mission. The patrol will come in contact with the enemy along the route. The enemy is a small insurgent unit intent on disrupting the patrol movement along the route. Upon contact, the patrol will return fire and call in artillery fire from the supporting artillery battery located in a nearby forward operating base. Upon suppression of the enemy unit with direct and indirect fire, the patrol will assault the enemy position. When the enemy unit is destroyed, the patrol will consolidate and request causality evacuations.

Assumptions:

- No voice or data message confirmations will be modeled (ie. “Roger”, “WILCO”, etc)
- Voice or data only messages. Hybrid messages are not modeled.

a. Phase 1

Conduct Patrol – The patrol will move along designated routes outlined in the pre-determined plan. The Squad Leader will continually communicate current position and location to the platoon leader and synchronize command and control of fire teams during movement. Table 10 defines the inputs to the simulation for phase 1.

b. Phase 2

Engage Enemy – The patrol taking small arms fire from a group of insurgents in urban terrain. The squad employs personal weapons for effective squad protection then requests Fire Support to suppress the enemy. Once the enemy is suppressed, the patrol assaults the enemy position to destroy remaining combatants. Table 11 defines the inputs to the simulation for phase 2.

c. Phase 3

Consolidate Position – The patrol establishes a secure boundary to repel a counter attack. One team has a casualty and requests a MEDEVAC for a wounded squad member. Table 12 the inputs to the simulation for phase 3.

Table 10: Phase 1 Simulation Events

From	To	Message	Type	Lines in Message	Start Time (min)	Frequency	# of Entities	Max #	Renege Time (sec)
FT	SQD LDR	FT Geographic Position	I	1	30	TRIA(18,20,22)	1	3	180
SQD LDR	HQ	SQD Geographic Position / Friendly Location	II	4	35	TRIA(20,30,40)	1	3	1200
FT	SQD LDR	FT Situation Update_Patrol	I	2	60	TRIA(15,20,25)	1	3	420
SQD LDR	HQ	SQD Situation Update_Patrol	II	2	65	TRIA(20,30,40)	1	3	1200
SQD LDR	FT	SQD Tactical Commands _Patrol (voice only)	I	1	0	TRIA(18,20,22)	1	5	60

Table 11: Phase 2 Simulation Events

From	To	Message	Type	Lines in Message	Start Time (min)	Frequency	# of Entities	Max #	Renege Time (sec)
FT	SQD LDR	FT Enemy Location Report	I	3	120	Once	1	1	180
SQD LDR	FT	SQD Terminal Weapons Guidance_Engage	I	3	121	Once	1	1	180
SQD LDR	HQ	SQD Enemy Locations	II	2	123	Once	1	1	1200
SQD LDR	HQ	SQD Situation Update_Engage	II	2	130	TRIA(8,10,12)	1	4	1200
FT	SQD LDR	FT Call for Fire	II	5	144	Once	1	1	420
SQD	HQ	SQD Call for Fire	I	5	150	Once	1	1	420
HQ	SQD	Fire Notification	I	1	160	Once	1	1	60
SQD	FT	SQD Fire Notification	II	1	166	Once	1	1	60
SQD LDR	FT	SQD Tactical Commands_Assault (voice only)	I	1	180	Once	1	1	60

Table 12: Phase 3 Simulation Events

From	To	Message	Type	Lines in Message	Start Time (min)	Frequency	# of Entities	Max #	Renege Time (min)
SQD LDR	FT	SQD Tactical Commands_Secure (voice only)	I	1	200	TRIA(4,5,10)	1	4	60
SQD LDR	FT	SQD Terminal Weapons Guidance_Secure	I	3	220	Once	1	1	60
FT	SQD LDR	FT MEDEVAC Request	I	3	230	Once	1	1	180
SQD LDR	HQ	SQD MEDEVAC Request	II	3	232	Once	1	1	180
FT	SQD LDR	FT_Causality Report	I	4	240	Once	1	1	420
SQD LDR	HQ	SQD Members Health	II	4	250	Once	1	1	1200

3. Results

Based on the described simulation inputs, the results are shown in Table 13. The Current, Advanced, and Future processed the same percentages of incoming (received) and outgoing (generated) messages with 45% and 30% respectively. Although they were able to process the same percentages of messages, the Future was the only alternative able to perform this without violating the workload threshold of 8.0 workload units as defined by Multiple Resource Theory by Wickens (1984). The Advanced followed just short of the threshold value with 8.5 workload units. The Current and Primitive required 81% and 150% more workload capacity of the squad leader to stay within the range of the threshold workload value. In addition a high max total workload, the Primitive alternative could not process outgoing (generated) messages as efficiently as the other three alternatives with only 19% of processed outgoing messages processed.

Table 13: Simulation Results

	Primitive	**Current**	**Advanced**	**Future**
% Processed Incoming Messages	10/22 = **45%**	10/22 = **45%**	10/22 = **45%**	10/22 = **45%**
% Processed Outgoing Messages	10/52 = **19%**	16/52 = **30%**	16/52 = **30%**	16/52 = **30%**
Max Total Workload	20.0	14.5	8.5	6.5

4. Model Limitations and Sensitivity

As with most models and simulations, accurate input data must be verify and validated with the results. Because this was a qualitative assessment of the different alternatives using a specific workload theory, not all results are sufficient to predict actual performance but provide a benchmark for comparison. The workload values have a particular sensitivity to the outcome of the simulation. Actual testing should be conducted on prototype devices with a sample size of actual users that can normalize the workload values of the different alternatives. This would lead to statistical variations in the workload values rather than using discrete values bound by anchor statements from previous human factor studies. Although the model has these limitations as described above, the level of confidence in the qualitative assessment of the alternatives is strong

enough to be used in the decision matrix and be evaluated for the sensitivity of the overall outcome of the recommended alternative.

D ALTERNATIVES SCORING

After the modeling and simulation analysis was completed, the team used the remaining weighting factors as criteria to further analyze the four recommended alternatives. This section describes the analysis completed for the system weight, power duration, usability and reliability.

1. Physical Weight Analysis

The physical weight of the communications system is extremely important to the person who must carry the system into battle. War-fighters have been known to saw off the end of their toothbrushes to reduce the weight so that they can carry more food and ammunition. Therefore the users hold physical weight to be of significant interest. The less weight the better. For that reason physical weight has a significant weighting factor. To determine the raw weight score for the four alternatives the components weights were added to determine an overall system weight. The total system weight for each alternative is displayed in Table 14 below. The actual components of each alternative are shown in Figure 22 through Figure 25 and are listed in Table 17 and Table 18. When the four alternatives are compared it should be noted that the future system combined weight is much less than the other systems. This is because the future system takes advantage of internal circuitry and weight reducing materials. The other three alternatives are very close in weight. When scoring the four alternatives the future system is ranked first.

Table 14: Physical Weight comparison

	Primitive	Current	Advanced	Future
Total Physical Weight	13 pounds	13.8 pounds	12.6 pounds	5.7 pounds

2. Power Duration (Battery Life) Analysis

A close second in importance to the user is the battery life of the system. The system must supply sufficient power to the system to permit effective communication or the system is of little use to the war-fighter. Work continues to provide a rechargeable

power source in the field, however, at this time no reliable rechargeable source is on the horizon. Therefore internal and replaceable batteries will be used for the foreseeable future. As can be seen from Table 15 below, battery life technology produces similar life for all four alternatives; however, the future system has a power regeneration component and thus can extend the total duration time for a much longer period. To determine the battery life the shortest battery life in the system was used as the defining raw score for the system. The future system again is ranked first.

Table 15: Power Duration comparison

	Primitive	Current	Advanced	Future
Power Duration = Battery life	6.5 hours	8 hours	8.5 hours	>10 hours

3. Usability Analysis

The usability analysis was an overall look at each system as a whole using a Likert Scale (1-7) where seven represents the system that is easiest to use. Eleven participants conducted a paper evaluation on the overall ease of use for each of the four alternatives. Statistical analysis was performed on the surveys and the median scores are presented in Table 16.

Table 16: Ease of Use Comparison

	Primitive	Current	Advanced	Future
Likert Score	4.5	5.0	6.0	7.0

4. Reliability Analysis

Reliability was selected as a quantitative measure to aid the team in decision making. The primary physical elements of the communications system for each alternative were defined and evaluated. Table 17 below shows each of the key components and their corresponding Reliability data. Data was captured via manufacturer printed material as well as market research on commercially available components. Though specific products or manufacturers declare unique Mean Time Between Failure (MTBF) values, there is enough testing and documented literature to provide essential trends for various products.

Each component's Reliability value (R-value) was calculated by using the reliability equations from Sage & Armstrong [4] below.

$$\lambda = 1/\mu$$

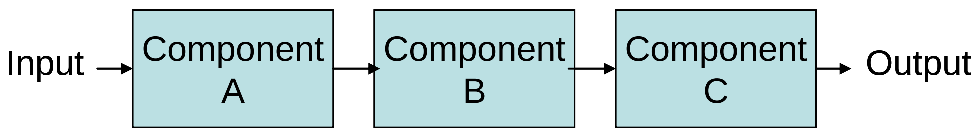
Where μ is the MTBF and

$$R(t) = e^{-\lambda t}$$

Where t is time

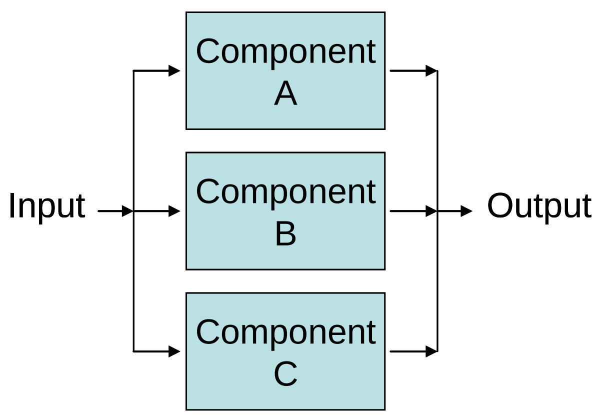
The minimum mission duration for the squad is approximately eight hours, and thus, eight was the value used for t in all calculations.

The R-value equations for systems in serial and parallel configurations, (Figure 27 and Figure 28 respectively) are given below:



$$R_{total} = R_A * R_B * R_C$$

Figure 27: Serial Reliability Equation



$$R_{total} = 1 - (1 - R_A) * (1 - R_B) * (1 - R_C)$$

Figure 28: Parallel Reliability Equation

The exact configuration of each alternative and the components used in each alternative defined the equations used which are also annotated in Table 17 below.

Table 17: Reliability Values – Components and Alternatives

MISSION DURATION	t =	8.00	hours

Component			MTBF = mu	lambda = 1/mu	R-value = e^ (-lambda*t)
A	BATTERY POWER		250	0.004000	0.96851
B	HEADSET / MIC		3900	0.000256	0.99795
C	LCD DISPLAY / SCREEN		50000	0.000020	0.99984
D	RADIO (Rx/Tx)		10000	0.000100	0.99920
E	KEYPADS		20000	0.000050	0.99960
F	COMMS PROCESSOR		10000	0.000100	0.99920
G	GPS UNIT		15000	0.000067	0.99947
H	HUMAN		2000	0.000500	0.99601
I	PIEZO ELECTRIC POWER		20000	0.000050	0.99960

Alternative Components	Alternative	R-Value
A*D*B*H	**PRIMITIVE**	**0.96189**
A*(1-(1-B)(1-E))*D*(1-(1-B)(1-C))*H	**CURRENT**	**0.96387**
A*(1-(1-B)(1-E))*D*F*G*(1-(1-B)(1-C))*H	**ADVANCED**	**0.96258**
I*(1-(1-B)(1-E)) *D*F*G*(1-(1-B)(1-C))*H	**FUTURE**	**0.99481**

Each alternative has a total system R-value based on the physical components used and their respective individual R-values, as well as the component layout, (serial, parallel or combinations of both). The total R-values for each alternative is provided in Table 17 above. It can be shown quantitatively that the Future Alternative has the highest total system reliability value (99.48% of an 8 hour mission).

E COST ANALYSIS

The methods described above develop a single utility value or score for each alternative that could be used to select the recommended alternative. However, doing so would be premature. Total utility is not the only important criterion left with which to judge the possible solutions. Each of the four alternatives is deemed feasible. These alternatives are further analyzed to determine level of added capability provided and at what cost in section IVD. The objective is to assess the Return on Investment.

1. Acquisition Costs

The cost of each alternative must be addressed. The cost is examined relative to Acquisition and Operations and Support (O&S) Cost. Each alternative may have significantly different costs which affect the decision as to which alternative should be pursued. It is not this team's job to make the final decision but to provide the stakeholders with a recommendation and the information they need to make intelligent decisions.

Each alternative is composed of a set of components. Some components are used in more than one alternative, but each alternative is unique. Most of the components are initially purchased from existing programs of record.

Spreadsheets were used to capture component data and to analyze both mathematically and graphically the relationships and relative costs between alternatives. In order to generate a cost estimate for a single alternative, the cumulative costs of the components were determined or estimated based on cost analysis

Table 18: System Components for Each Alternative

Primitive Alt	Current Alt	Advanced Alt	Future Alt
PRC 152 (ECO pg 26)	PRC 152 (ECO pg 26)	PRC 154 (EDM) Incr 1 (RR CPD pg 4)	PRC 154 (EDM) Incr 2 (RR CPD pg 4)
PRC 153 (ECO pg 19)	PRC 153 (ECO pg 19)	PRC 153 (ECO pg 19)	
Headsets (included with radio)	Headsets (included with radio)		Heads Up Display[3] Internal Earpiece[5]
Handheld GPS (ECO pg 23)	Laptop (MR-1) (embedded GPS) (ECO pg 29)	Touch Pad[2]	
GPS Battery	Laptop Battery[1]	Touch Pad Battery[2]	
Radio Battery[4]	Radio Battery[4]	Radio Battery[4]	Piezo-electric Power

[1]http://www.laptopbatterydepot.com/shopping/productdetails.asp
[2] sales@glaciercomputer.com
[3]http://www.myshopping.com
[4]http://www.buchmann.ca/article20-page1.asp
[5]http://customearpiece.com/category.php?id=18&gclid=CN7ly7aA5pwCFRkpawodp08gFQ

The costs are derived from both parametric cost analysis based on subject matter expert inputs and actual costs based on published documentation from respective programs while other costs were obtained through internet research. SMEs provided unit prices, system specifications (including size, weight and power data used in other sections of this paper), and capability estimates based on current systems of record. The SMEs were able to provide a rough estimate when actual cost data for the respective system was unavailable. Unknown variables such as integration costs were given best effort analyses to determine reasonable cost ranges.

The costs for each of the alternatives, broken down by components and compiled into an acquisition cost, are displayed in Figure 29 through Figure 32.

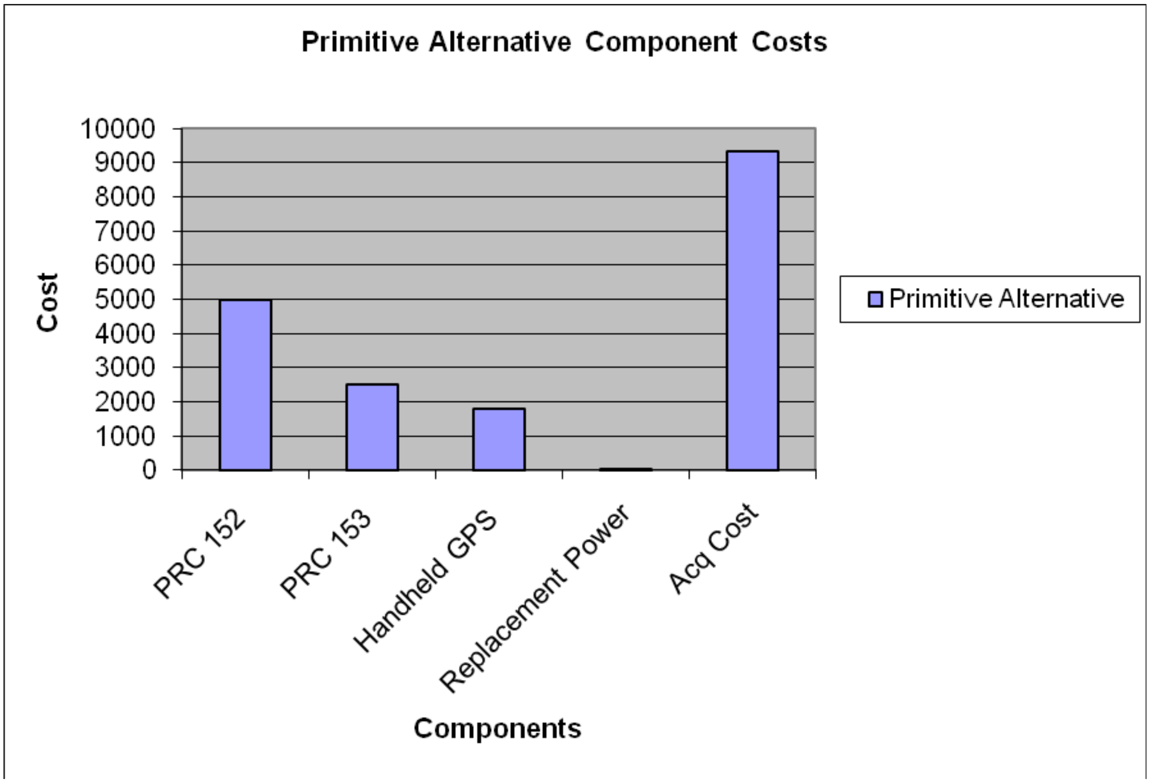


Figure 29: Primitive Alternative Component Costs

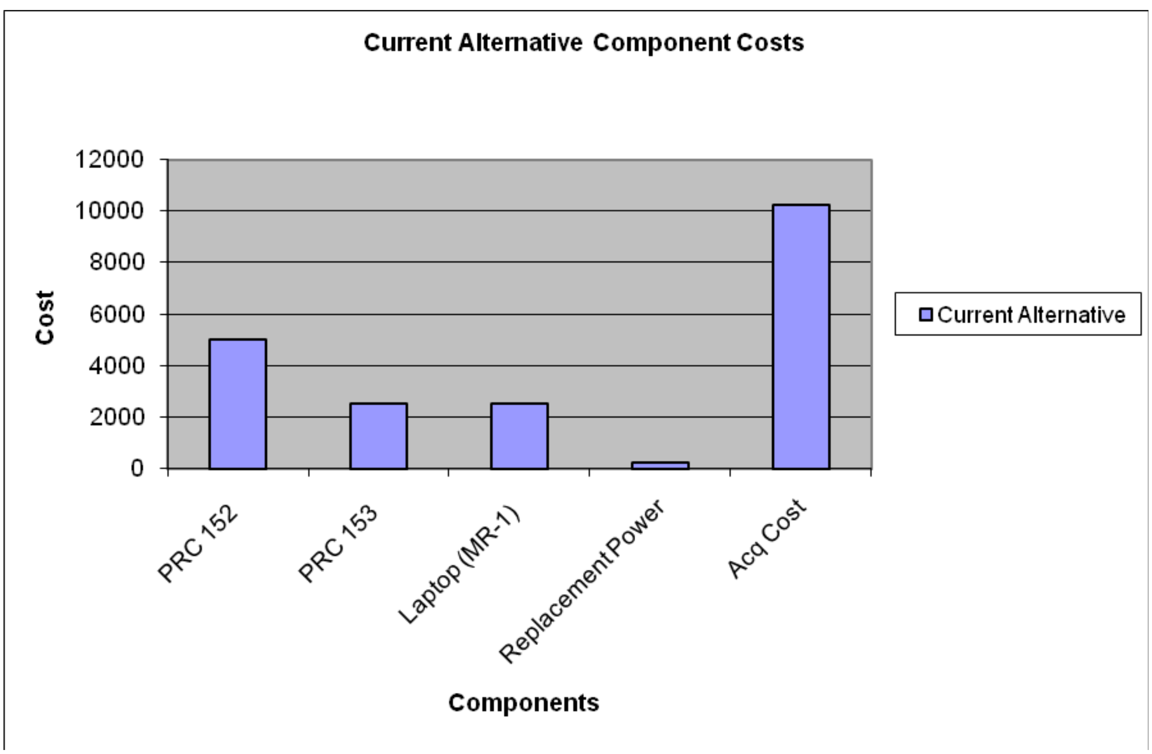


Figure 30: Current Alternative Component Costs

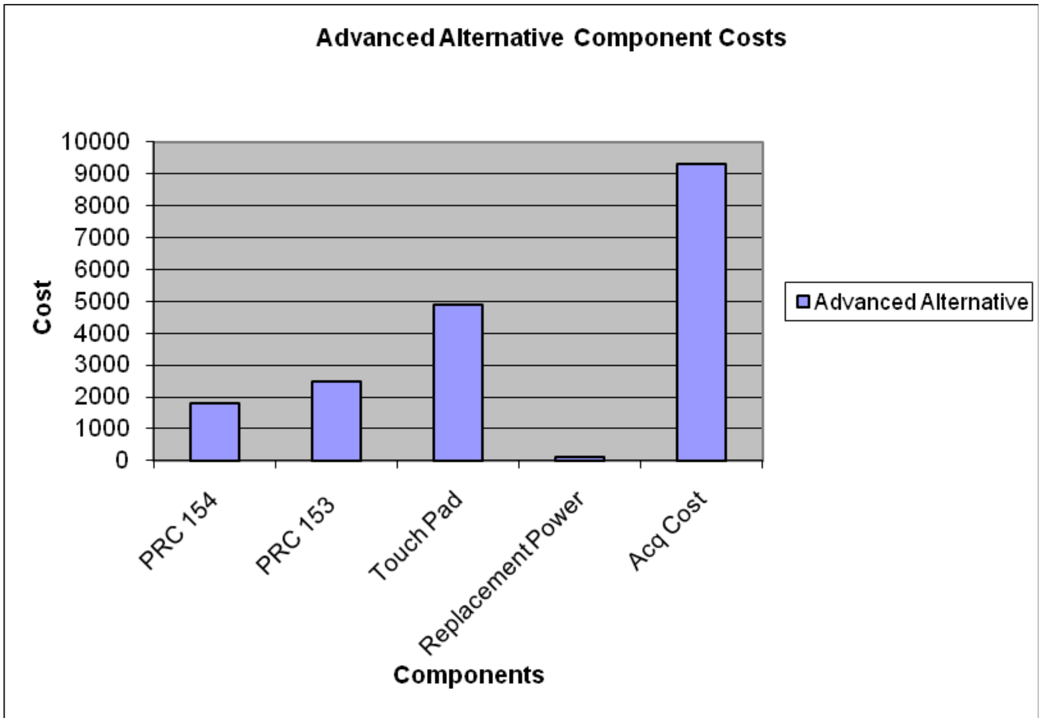


Figure 31: Advanced Alternative Component Costs

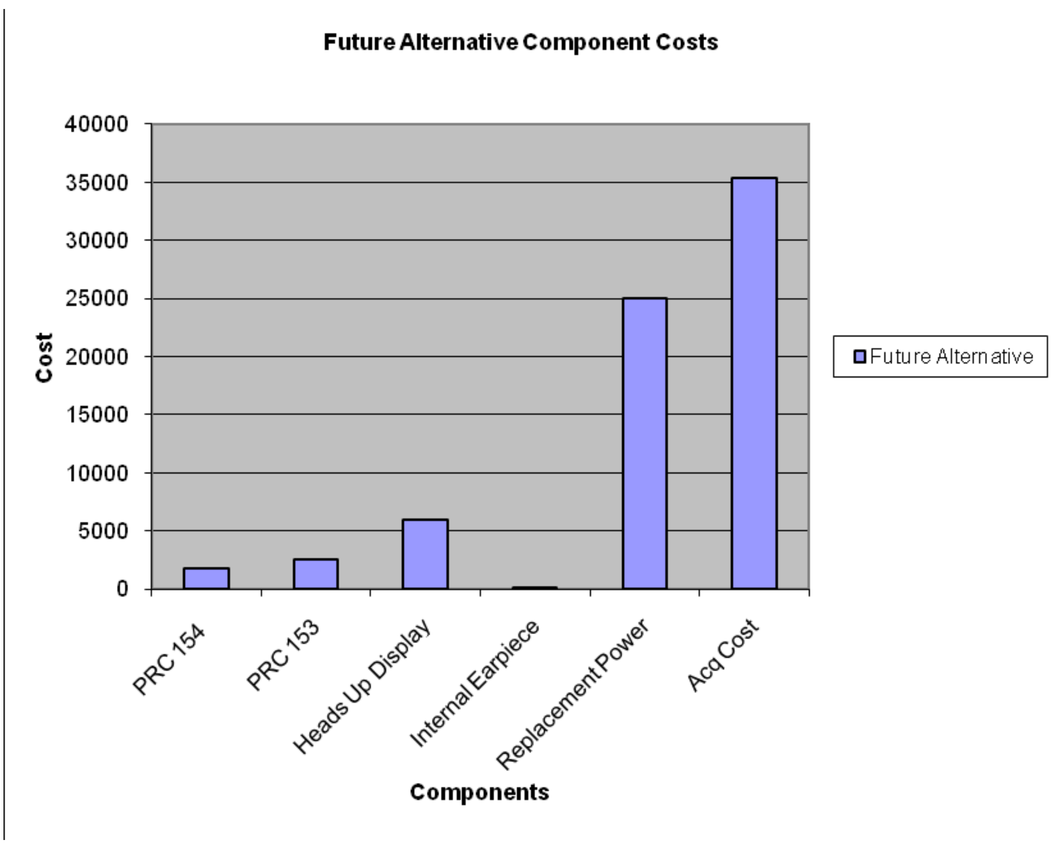


Figure 32: Future Alternative Component Costs

The acquisition costs totals for each alternative, as compared to the other alternatives, are shown in Figure 33.

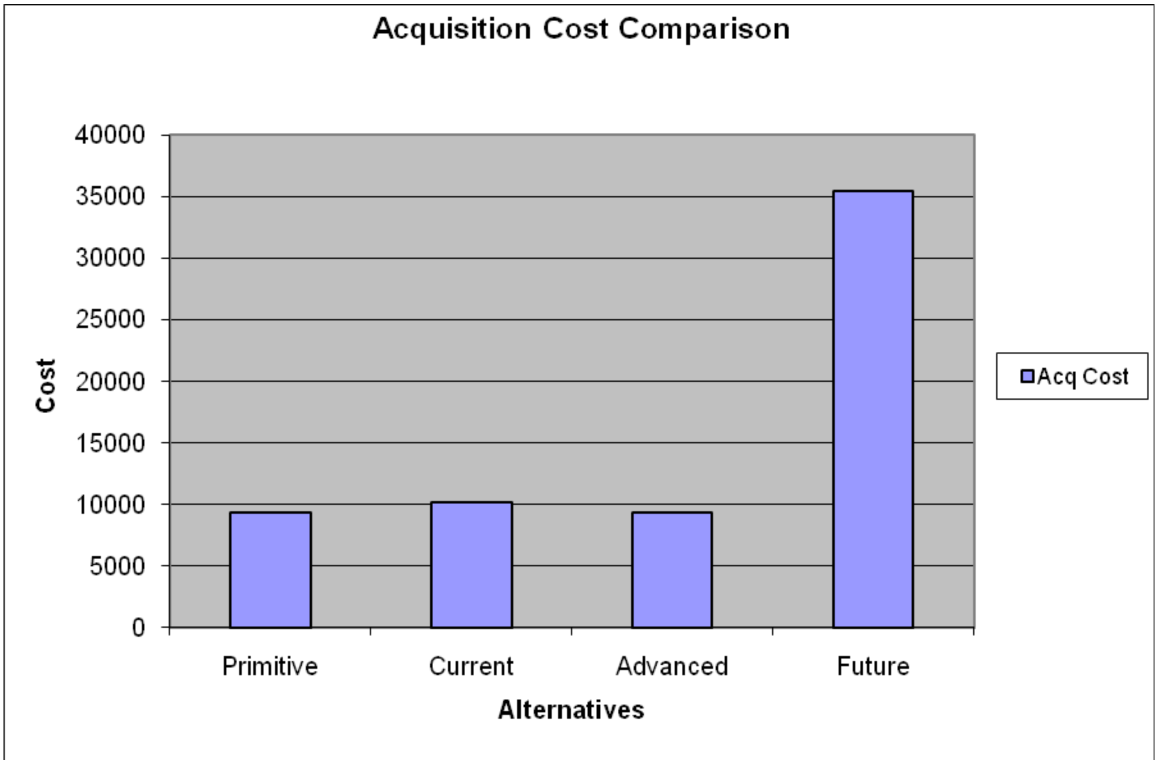


Figure 33: Acquisition Cost by Alternative

2. Operations and Sustainment Costs

"O&S has historically been the largest portion of Life Cycle Cost. A complete estimate of O&S costs will typically include the costs of personnel, consumables, goods and services, and sustaining support and investments associated with the peacetime operation of a weapon system. Operating and support costs normally constitute a major portion of system life- cycle costs and, therefore, are critical to the evaluation of acquisition alternatives." (Defense Technical Information Center, 1992). The Rifleman Radio CPD supports this data and states that the AN/PRC-154, which provides a major portion of functionality for the Advanced and Future Alternatives, has O&S costs that are 65% of the Total Life Cycle costs.

The O&S costs for the hardware are shown in Figure 34 and are based upon the three to five year hardware replacement standard and the software upgrade standard every 12 to 18 months. The normal radio replacement plan is a 7-10 year cycle. The O&S

costs were estimated for a ten year period. All of these facts are taken into consideration in determining the O&S costs for the alternatives that include the AN/PRC-154 as a component. The O&S costs are further extrapolated to the other alternatives based on the similarity of the systems.

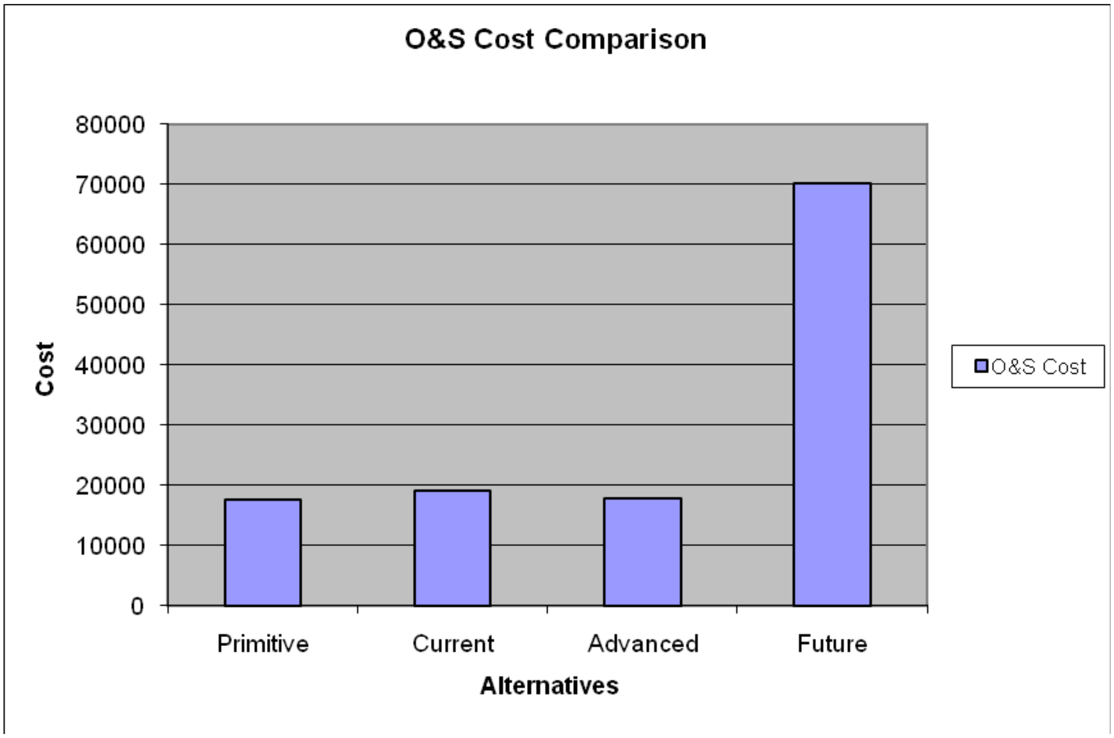


Figure 34: Operational and Supportability Costs

The Rifleman Radio CPD presents O&S as the largest cost contributor in the PRC 154 Total Life Cycle costs. The O&S costs for the hardware are based upon the maximum of the three to five year replacement standard and the software on an 18 month replacement standard. The normal radio replacement plan is a 7-10 year cycle. The fielding schedule for PRC 154 is FY11-18. Additional replacement or upgrade fielding is planned at the end of the AN/PRC-154 lifecycle.

3. Total Life Cycle Costs

The Total Life Cycle Costs, as defined for the purposes of this project, are the combination of the Acquisition and O&S costs as shown in Figure 35.

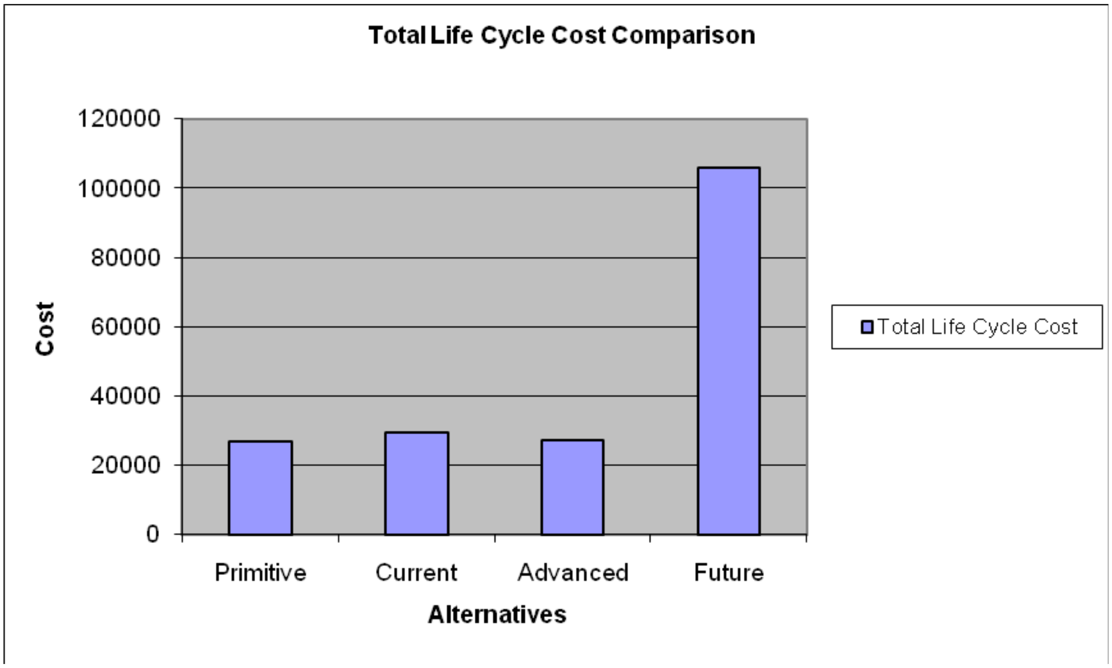


Figure 35: Total Life Cycle Costs

The Primitive, Current and Advanced alternatives costs all fall within a $2300 range. The Future alternative cost is between three and four times as much as the others.

F ALTERNATIVES SCORING RESULTS AND SUMMARY

After the execution of the SE process, the modeling and simulation, capturing system data and evaluating the results from all of the analysis efforts described above, the teams final effort was completing the Decision Analysis process. The team was prepared to make a recommendation for a specific alternative and COA, based on the quantitative data shown in Table 19. It is clear from the Capability vs. Cost mappings in Figure 36 that the best "bang for the buck" is the Advanced Alternative.

Table 19: Alternative Scoring Summary

	Alternative					Primitive			Current			Advanced			Future		
Benefits	**Metric**	**Weighting factor**	**Best**	**Threshold value**	**Objective value**	**Raw**	**Rank**	**Weighted Rank**	**Raw**	**Rank**	**Weighted Rank**	**Raw**	**Rank**	**Weighted Rank**	**Raw**	**Rank**	**Weighted Rank**
Weight	pounds	20	less	***10lbs***	***5lbs***	13	3	6.7	13.8	4	5.0	12.6	2	10.0	5.7	1	20.0
Battery life	hours	15	longer	***6hr***	***8hr***	4.5	1	3.0	4.5	3	5.0	6	2	7.5	8	1	15.0
Ease of use	1 though 7 scale	15	more	***4***	***7***	4.5	4	3.8	5	3	5.0	6	2	7.5	7	1	15.0
Reliability - MTBF	%	15	more	***90***	***99***	96.19	3	5.0	96.39	2	7.5	96.26	2	7.5	99.48	1	15.0
Workload	workload units	15	less			20	4	3.8	14.5	3	5.0	8.5	2	7.5	6.5	1	15.0
Incoming message process	%	10	more	***1#***	***2#***	45	1	10.0	45	1	10.0	45	1	10.0	45	1	10.0
Outgoing message process	%	10	more	***1#***	***2#***	19	2	5.0	30	1	10.0	30	1	10.0	30	1	10.0
Total Score		100						37.2			47.5			60.0			100.0
Cost ($)K						$2.7			$2.9			$2.7			$105.7		
Bang per Buck								13.8			16.4			22.2			0.9

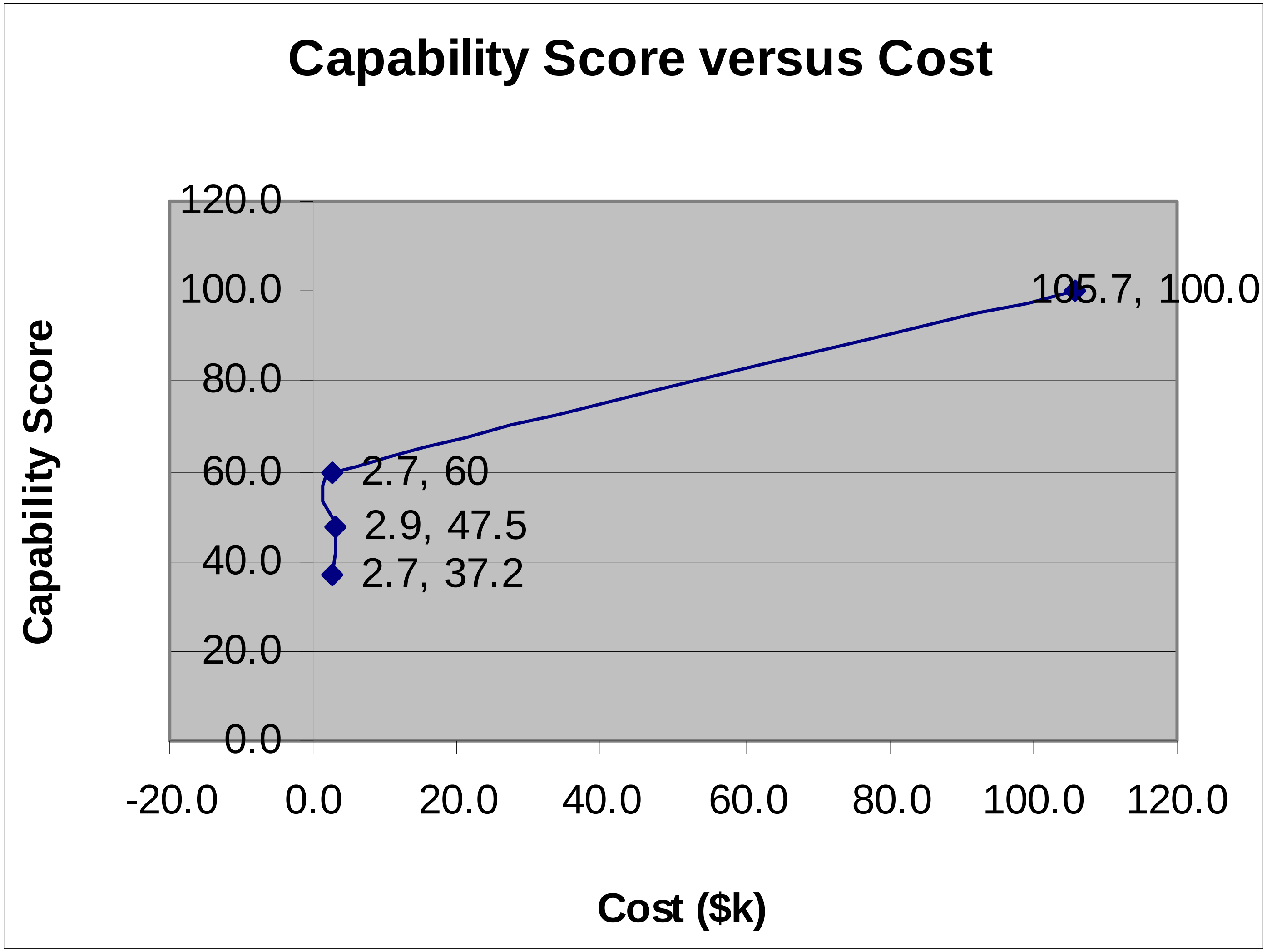


Figure 36: Capability vs. Cost (“Bang for the Buck”)

V CONCLUSIONS AND RECOMMENDATIONS

The Team Marine System Engineering team effectively applied the practices, processes, and analysis of the System Engineering Design Process (SEDP) in order to understand the needs of the customer. The team considered non material or DOTLPF alternatives. Non-material alternatives were not considered to be viable to solve the capability problem. Four (4) possible material alternative solutions were developed to meet the customer requirements. These four alternative solutions were derived from the Functional Architecture, Physical Architecture, and Operational Architecture.

Through feasibility screening, modeling and simulation, decision scoring, risk analysis and cost analysis the team determined that an evolutionary development effort would be the best course of action for MCSC to undertake. In the near-term, the team recommends pursing the Advanced Alternative. This alternative is the best, "bang for the buck" integrated solution. As systems mature and technologies become available the team anticipates that MCSC will be able to evolve into the Future Alternative. Currently, the future alternative is not ready for production and is in the Concept Development Phase (DoD acquisition cycle).

The team recommends that PM MERS continue the acquisition and development of the Advanced Alternative, migration to the Future Alternative, and consider the following:

- Conduct a Life Cycle cost estimate for the Advance approach to determine logistics support;
- Conduct a Human Factors study for current fielded Squad Leader communications in order to identify shortfalls in capability and to address these shortfalls in the next generation communication system;
- Include the results of this team's effort as the foundation for future analysis and development.

VI LIST OF REFERENCES

(1) Bierbaum, C.R., Szabo, S. M., Aldrich, T. B. (1987). *A comprehensive task analysis of the UH-60 mission with crew workload estimates and preliminary decision rules for developing a UH-60 workload prediction model, Vol I, II, III, IV, Ft. Rucker, AL.*

(2) Blanchard, B.S., & Fabrycky, W.J. (2006). *Systems Engineering and Analysis,* 4th Edition.

(3) Buede, D. (2000). The Engineering Design of Systems, *Models and Methods*

(4) Buede, D.M. (2000). The Engineering Design of Systems – *Models and Methods*.

(5) Defense Technical Information Center. (1992). OSD Cost Analysis Improvement Group, *Operating and Support Cost Estimating Guide*.

(6) Defense Technical Information Center. (2009). *Joint Publication 1-02, 354.*

(7) Field Manual, FM 6-02.53, (2008). Tactical Radio Operations

(8) Forsberg, K., Mooz, H., and Cotterman, H., (2000). *Visualizing Project Management*, 2^{nd} Edition

(9) Grady, J.O. (2009). Universal Architecture Description Framework. *The Journal of the International Council of Systems Engineering*, *Vol. 12*, *No. 2*, 91.

(10) Joint Requirement Oversight Council. (2008). *Blue Force Tracking (BFT) Position Location Information (PLI) Security and Classification Policy Brief*

(11) Joint Requirement Oversight Council. Memorandum, *Blue Force Tracking (BFT) Position Location Information (PLI) Classification and Security Policy*

(12) Joint Requirements Oversight Council. *Memorandum 071-08*

(13) Keller, J. (2002). Proceedings. *Human Performance Modeling for Discrete-Event Simulation: Workload.*

(14) Kelton, W.D., Sadawski, R. P., & Sturrock, D. T. (2007). *Simulation with Arena, 9*

(15) Maier, M.W., and Rechtin, E. (2002). *The Art of Systems Architecting*, 2nd Edition

(16) Marine Expeditionary Rifle Squad (MERS) Architecture Final Practicum Project Report, 11 June 2008

(17) McCrasken, J. H., Aldrich, T. B. (1984). Analysis of Seelcted LHX Mission Functions, *Implications for Operator Workload and System Automation Goals, Ft. Rucker, AL.*

(18) Mitchell, D. K. (2000). *Mental Workload and ARL Workload Modeling Tools*.

(19) MITRE, (2008). MAGTF C2 Transformation Task Force, *Draft: CAPSET V Concept of Employment (COE), Version 0.2*

(20) MITRE. (n.d.). *C2_SA Study Interoperability Analysis, MTR070229*

(21) National Information Assurance. (2006). *CNSS Instruction No. 4009.* Ft. Meade, Maryland: U. S. Government Printing Office.

(22) National Institute of Standards and Technology. (1993). Federal Information Processing Standards Publication. *Integration Definition for Functional Modeling,183*

(23) Paulo, E. (2006). System Integration *4007*, Fundamentals of System Engineering [Powerpoint slides]. Retreived from https://nps.blackboard.com

(24) Rifleman Radio. (2008). *Capability Production Document Version 2.1.0.*

(25) Sage, A.P. and Armstrong, J.E. (2000). *Introduction to Systems Engineering*

(26) Unified Command Plan. (2008).

(27) United States Marine Corps Rifle Co, (2008). *Infantry Battalion Communication*, presented at MARCENT G-6.

(28) United States Marine Corps. (1991). Warfighting Publications (MCWP) 3-11.2 Marine Rifle Squad

(29) United States Marine Corps. (2008). Marine Expeditionary Unit Operations in Afghanistan, 24th Marine Expeditionary Unit (MEU), *Lessons and Observations from Operation Enduring Freedom (OEF).*

(30) United States Marine Corps. (2009). Center for Lessons Learned. Retrieved May 6, 2009, from https://www.mccll.usmc.mil (CAC enabled)

(31) Wickens, C. D. (1984). Engineering Physiology and Human Performance.

(32) Wickens, C. D., Lee, J. D., Liu, Y., Becker, S.G. (2004). *An Introduction to Human Factors Engineering*. 2nd Edition

(33) Wiles, R, LT FASWTC, N72, Personal Interview, November 14, 2007.

(34) Wisnosky, D.E. (2006). *DoDAF, Wisdom, 113*

(35) Wideman, R. M. (1992). Project and Program Risk Management, *A Guide to Managing Project Risk and Opportunities.*

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APPENDIX A

A PROJECT TEAM AND STRUCTURE

1. Team Structure

Team Marine consisted of 10 members, as seen in Figure 37 below,each with various educational backgrounds and systems engineering experiences. The team nominated Mr. Larry Bochenek and Mr. Jeff Dixon as the Project Lead and Co-Lead respectively.

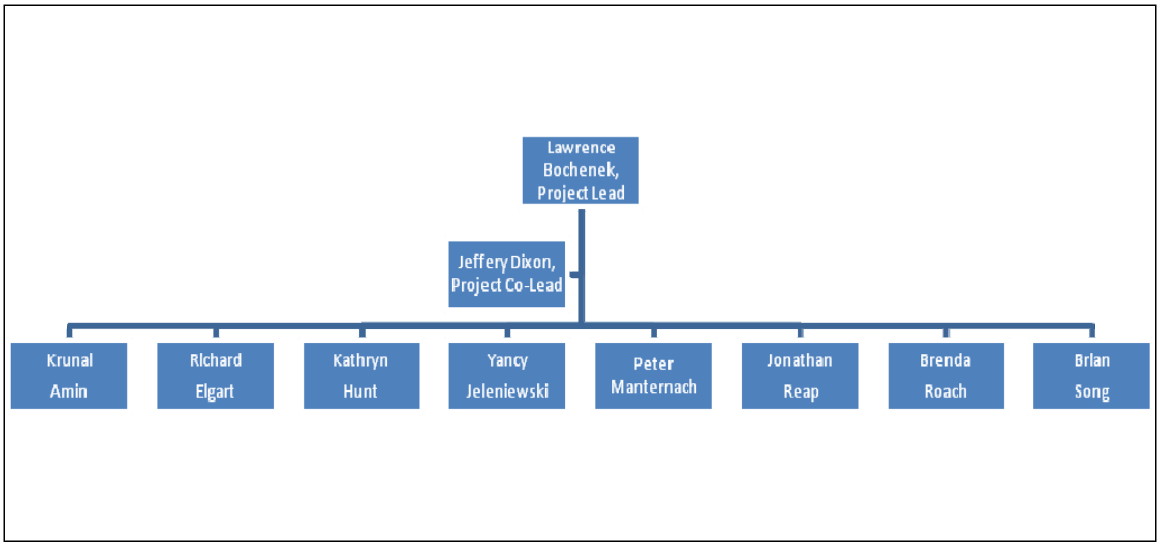

Figure 37: Team Marine Members

Each member was assigned tasking or volunteered to work on specific elements of the project. Some efforts were executed as individuals and many others were executed as teams, as seen below in Figure 38: Team Marine Functional Area Teams.

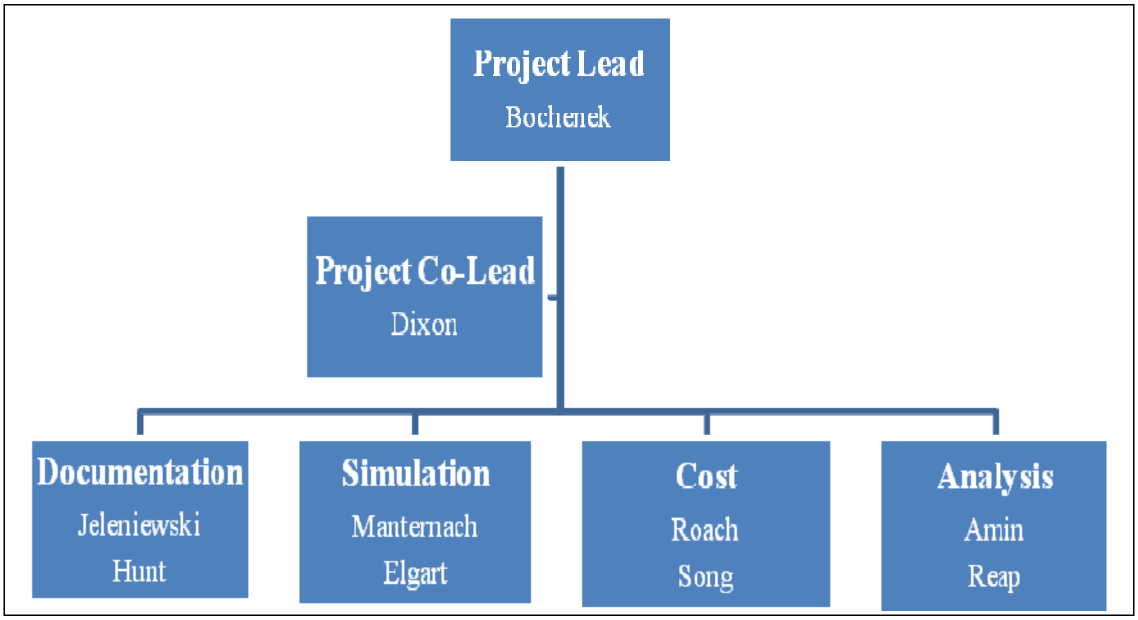

Figure 38: Team Marine Functional Area Teams

Figure 38 shows how the team divided the efforts into functional areas and worked as an Integrated Product Team (IPT).

IPT meetings and collaboration sessions were established to meet program objectives within each program phase. As an IPT completed the assigned tasking the IPT lead reported to the Project lead the status, and members were then reassigned as necessary.

APPENDIX B

B PROJECT RISK MANAGEMENT

1. Risk Management Analysis

The goal of the Team Marine Risk Management Program is to implement methods and alternatives that keep overall program risk low. To accomplish this goal, Team Marine uses a centrally managed and executed risk strategy. The risk strategy is to identify potential risk items and events as early as possible, develop mitigation alternatives or handling options and reduce the potential impacts before the items cause serious cost, schedule and/or performance problems. The entire team participates in the Risk Management Board. This method is a proactive process to detect and mitigate risk elements. There are many elements of risk such as Programmatic, Cost, Schedule, Quality, Time, Human Resources, Communication, Performance as well as Organizational. *(Wideman, 1992).* For the purposes of this report, only performance risks will be evaluated.

By definition, risk is defined as an event whose occurrence could jeopardize the successful completion of the project. Risk is the measure of the potential future inability to achieve project objectives within defined cost, schedule and performance constraints Project risks are thus identified and accessed for the probability of occurrence and its impact on successful completion of the project.

2. Risk Management Process

Risk management process will utilize two key factors to manage risk. The two key factors are probability/likeliness of occurrence and consequence of occurrence. The probability of occurrence is defined in terms of percentage values with respect to schedule and performance. The levels of likelihood of an occurrence are directly related to the probability of occurrence and are further defined in Table 20.

Table 20: Likelihood of Occurrence levels

Probability/Likelihood of Occurrence - Performance		
Level	Probability of Occurrence	Definition
1	$0.0 < P \leq 0.3$	Low likelihood

2	$0.3 < P \leq 0.5$	Low to medium likelihood
3	$0.5 < P \leq 0.7$	Medium likelihood
4	$0.7 < P \leq 0.9$	Medium to high likelihood
5	$0.9 < P \leq 1.0$	High likelihood

The consequence of occurrence is the impact on successful completion of the project. The consequence of occurrence is defined in terms of percentage values with respect to schedule and performance. The specific ‘Consequence of Occurrence’ levels are directly related to percentile impacts and are further defined in Table 21.

Table 21: Consequence of Occurrence levels

Consequence of Occurrence - Performance		
Level	Consequence of Failure	Definition
1	$0\% < C \leq 10\%$	Minimal impact
2	$10\% < C \leq 20\%$	Minimum to medium impact
3	$20\% < C \leq 30\%$	Medium impact
4	$30\% < C \leq 40\%$	Medium to Major impact
5	$C > 40\%$	Major impact

Based on probability and consequence distribution as stated above, team marine will use the following four step risk management approach.

a. Step 1: Risk Identification

The purpose of risk identification is to identify risk and evaluate its relative severity. The evaluation of risk identification is based on scale ranging from 1 to 5. A rating of 1 is implies lowest severity and a rating a 5 implies highest severity. The end result of risk identification is risk mapping matrix value of probability of particular failure with respect to consequence of that particular failure. The risk value will be identified in the form of a risk cube in risk tracking and control phase (step 4), where several project risks could be identified.

b. Step 2: Risk Assessment

Risk is assessed based on likelihood of occurrence and severity of the consequences to the overall project. The risk assessment is a calculated Expected

Consequence value. Risk is calculated as a product of probability of failure and consequence of failure.

*Expected Consequence (EC) = Probability of failure (Pf) * Consequence of failure (Cf)*

c. Step 3: Risk Mitigation

Once the risk has been accessed, the following options can be exercised to handle the specific project risks:

- Accept the risk and do nothing more
- Mitigate the risk by expending team resources to reduce likelihood and/or severity
- Transfer the risk by an agreement with another party to eliminate likelihood and/or severity
- Deal with the risk as it occurs

d. Step 4: Risk Tracking and Control

Risk tracking will be accomplished by a risk mapping matrix to simplify and illuminate the risk management process and status. The graphical representation of risk mapping matrix is shown below in Figure 39.

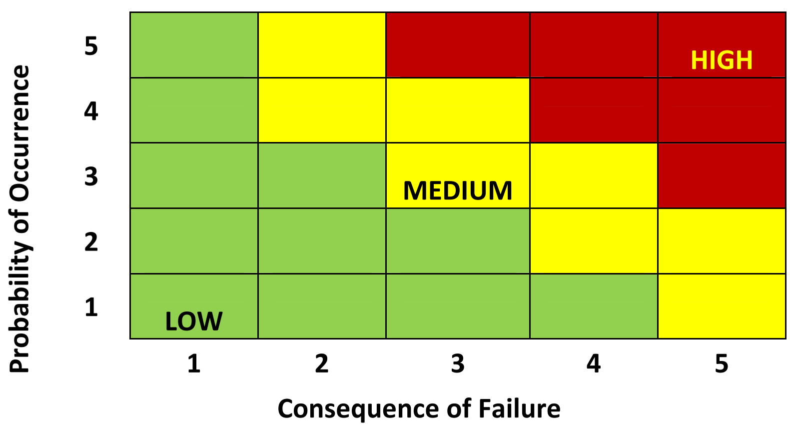

Figure 39: Generic Risk Mapping Matrix

All risk items pertaining to the project are identified, with higher risk items prioritized over lower risk items.

3. Program Risks

a. Risk #1: Not improving communications capability

Risk Identification: The team has identified recommending an unimproved communications capability as a risk. The risk is identified as a result of the identification

of the primitive alternative. If through our analysis we determine that the primitive alternative is our recommendation, we will have failed to provide the stakeholders with their requested capabilities.

Risk Assessment: The risk assessment for not recommending an improved communications capability was identified as a minor risk with a rating of level 3. The levels of probability and consequence with respect to performance are calculated below:

Probability/Likelihood of occurrence with respect to performance = P = 0.3 = Level 2

Consequence of occurrence with respect to performance = C = 40% = Level 5

Therefore, using Expected Consequence criteria, we calculated the following

*EC with respect to performance = 0.3*0.40 = 0.33 = 12% = Level 2*

According to the EC criteria, the consequence impact is of a minimum to medium level in terms of performance.

Risk Mitigation: The consequence of risk with respect to performance being low, the team unanimously agreed to accept the risk and do nothing more, because the SE process employed was expected to prevent the occurrence of recommending an unimproved communications capability.

Risk Tracking and Control: Figure 40 represents the tracking and control of Risk #1.

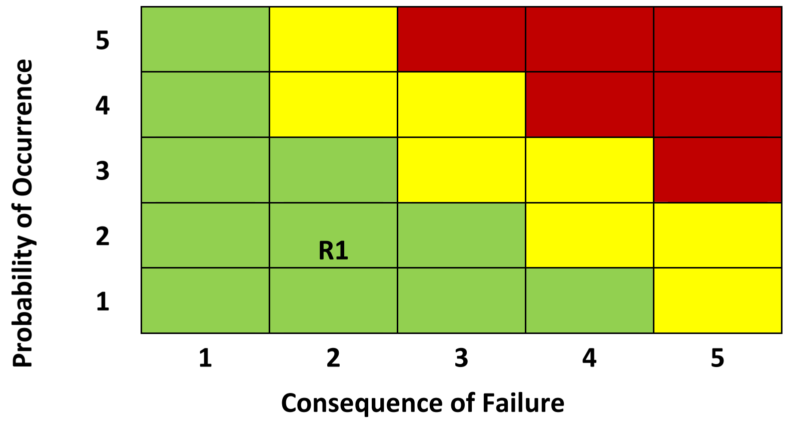

Figure 40: Risk #1 Mapping

b. Risk #2: Increasing weight beyond acceptable range

Risk Identification: Each of the alternatives beyond the primitive requires an increase or modification in components which could result in an increase in weight beyond the acceptable range. One of the goals of this project is to minimize the weight of the system. The severity of the risk is rated at 4 on a scale of 5.

Risk Assessment: The probability and consequence of increasing the system weight beyond the acceptable range was identified as an elevated risk with a rating level of 4. The levels of probability and consequence with respect to performance are calculated below:

Probability/Likelihood of occurrence with respect to performance = P = .8 = Level 4

Consequence of occurrence with respect to performance = C = 70% = Level 5

Therefore using Expected Consequence criteria, we get the following

*EC with respect to performance = 0.8 * 0.7 = 0.56 = 56% = Level 5*

According to the EC criteria, the consequence is at the maximum level in terms of performance.

Risk Mitigation: Since the consequence of the risk with respect to performance is at the highest level, the team unanimously agreed to mitigate the risk by first determining the acceptable weight range. Secondly, the team assigned the greatest weighting factor to system weight. As a result of the mitigation plan, the revised values for

probability/likelihood of occurrence and consequence of occurrence with respect to performance were re-calculated below:

Probability/Likelihood of occurrence with respect to performance = P = 0.2 = Level 1

Consequence of occurrence with respect to performance = C = 5% = Level 5

Therefore using Expected Consequence criteria, we get the following

*EC with respect to performance = 0.2 *0.05 = 0.01 = 1% = Level 1*

The mitigation provided the team with a revised EC value for performance which was reduced from 56% to 1%.

Risk Tracking and Control: Figure 41 is the mapping matrix for Risk #2 and represents the tracking and control of risk before and after the mitigation.

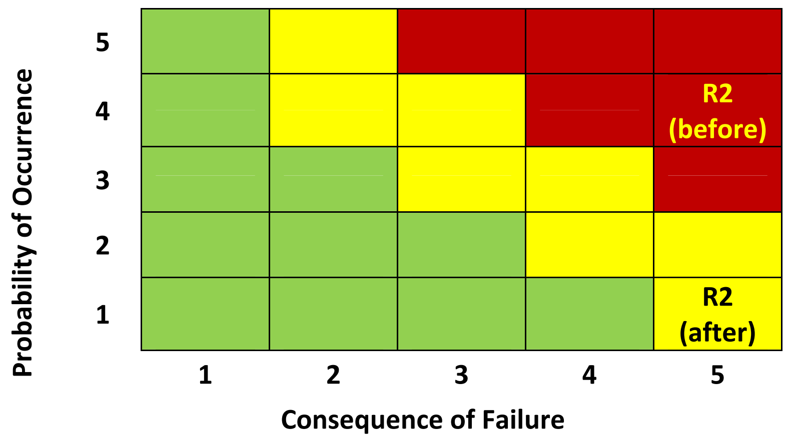

Figure 41: Risk #2 Mapping

As shown in Figure 41, Risk #2 was mitigated to a much more controllable and acceptable level.

c. *Risk #3: Recommending a solution that is too complicated*

Risk Identification: Certain of the alternatives contain highly technical components such as the heads up display, piezoelectric power, and touch pad computers. These components may require much more training and higher order thinking than that required by the current system. The severity of the risk is rated at 4 on a scale of 5.

Risk Assessment: The probability and consequence of Risk #3, (recommending a solution that is too complicated), has a definite impact on the project. The levels of probability and consequence with respect to performance are calculated below:

Probability/Likelihood of occurrence with respect to performance = P = 0.8 = Level 4

Consequence of occurrence with respect to performance = C = 40% = Level 4

Therefore using Expected Consequence criteria, we get the following

*EC with respect to performance = 0.8 *0.4= 0.36 = 36% = Level 4*

According to EC criteria, the consequence is at a medium to major level in terms of performance.

Risk Mitigation: Since the consequence of risk with respect to performance is at a medium to major level, the team unanimously agreed to mitigate the risk by evaluating the ease of use of the systems. As a result of the mitigation plan, the team was able to manage and revise the risk assessment. Both the probability/likelihood of occurrence and consequence of occurrence were recalculated based on the mitigation with the revised values below:

Probability/Likelihood of occurrence with respect to performance = P = 0.3 = Level 2

Consequence of occurrence with respect to performance = C = 40% = Level 4

Therefore using Expected Consequence criteria, we get the following:

*EC with respect to performance = 0.3 * 0.4 = 0.12 = 12% = Level 2*

Therefore the revised EC values for performance are reduced from 36% to 12% and thus lowering the consequence from major to medium to medium to minimal level.

Risk Tracking and Control: Figure 42 represents the tracking and control of Risk #3 before and after the mitigation. This represents a risk that is more acceptable to adopt.

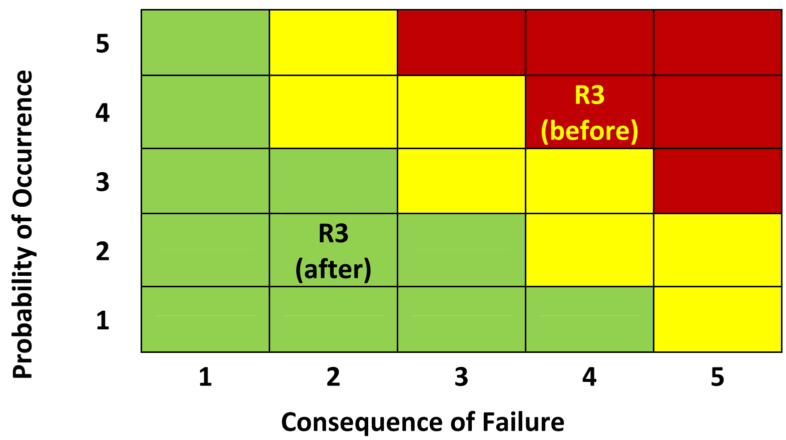

Figure 42: Risk #3 Mapping

d. Risk #4: Technology Maturation

Risk Identification: The technology maturation for some components included in the Future Alternative is below standard. A capability that is non-existent is rated at a scale of 4 out of 5, both in terms of probability and consequence.

Risk Assessment: The probability and consequence of non-existent solutions and architectures could have major impacts in addressing objectives and effective needs of the system. The levels of probability and consequence with respect to performance are calculated below:

Probability/Likelihood of occurrence with respect to performance = P = 1.0 = Level 4

Consequence of occurrence with respect to performance = C = 90 % = Level 5

Therefore using Expected Consequence criteria, results in the following.

*EC with respect to performance = 1.0 *0.9 = 0.9 = 90 % = Level 5*

According to EC criteria, the consequence impact is of medium to major level in terms of performance.

Risk Mitigation: Since the consequence of this risk is high with respect to performance, the team unanimously agreed to mitigate risk by attaching a large cost to the undeveloped technology.

As a result of the mitigation to technology maturation the following risk parameter was revised for probability/likelihood of occurrence.

Probability/Likelihood of occurrence with respect to performance = P = 0.3 = Level 1

Therefore using Expected Consequence criteria, we get the following

*EC with respect to performance = 0.3 *1.0 = 0.30 = 30% = Level 4*

Therefore the revised EC values for performance are reduced from 90% to 30% and thus lowering the consequence from the High level to the Medium to Major level.

Risk Tracking and Control: The following risk mapping matrix represents the tracking and control of risk before and after the mitigation.

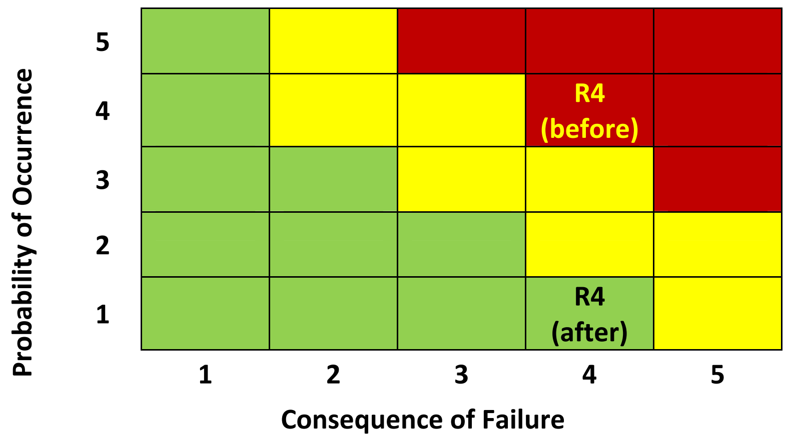

Figure 43: Risk #4 Mapping

4. Project Risk Status

Table 22 summarizes the overall project risks post risk mitigation efforts.

Table 22: Project Risk Summary

RISK ID	Likelihood	Consequence
R1	Level 2	Level 2
R2	Level 1	Level 5
R3	Level 2	Level 2
R4	Level 1	Level 4

Figure 44 below, provides an overall graphical representation of all identified project risks in a single risk mapping matrix.

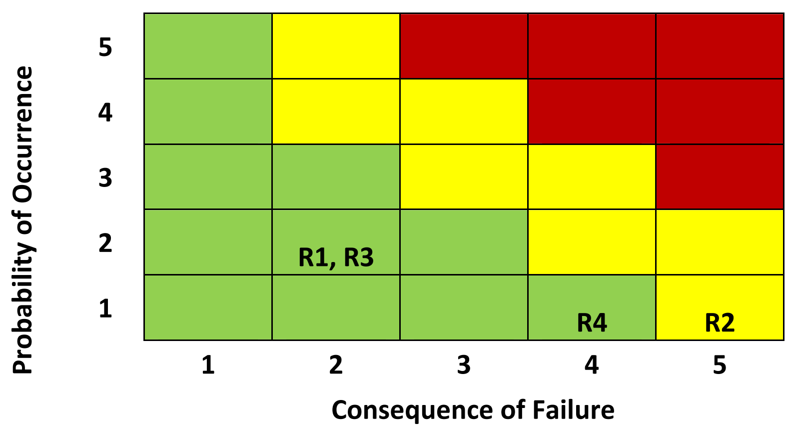

Figure 44: Mapped Project Risks

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APPENDIX C

C MARINE EXPEDITIONARY RIFLE SQUAD (MERS) ARCHITECTURE VIEWS

Table 23: Operational Information Exchange Matrix (OV-3)

Architecture View	Needline ID	Sending Node	Sending Hierarchy ID	Sending Activity	Information Exchange (IE)	Receiving Node	Receiving Hierarch	Receiving Activity	Criticality Code	Criticality	Information Type	Classification Level
MERS Combat Operations	NL 4	PLT Cmdr		External	Commander Guidance	Squad Ldr	A1.1	Assign Mission	1	Yes	Voice	Secure
MERS Combat Operations	NL 8	Squad Ldr	A1.2	Determin Mission Profile	SMEAC Brief	Fire Team	A1.3	Brief the Squad	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Squad Ldr	A1.3	Brief the Squad	SMEAC detail request	Fire Team	A1.3	Brief the Squad	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Squad Ldr	A1.3	Brief the Squad	Mission Provision Requirement	Fire Team	A1.4	Provision the Squad	2	Yes	Voice/Data	Unclassified
MERS Combat Operations	NL 8	Fire Team	A1.4	Provision the Squad	Fire Team Provision Status Report	Squad Ldr	A1.4	Provision the Squad	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 4	Squad Ldr	A1.4	Provision the Squad	Squad Provision Status Report	PLT Cmdr		External	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 8	Squad Ldr	A2.1	Execute Route	Command to execute Squad mission	Fire Team	A2.1	Execute Route	2	Yes	Voice/Data	Unclassified
MERS Combat Operations	NL 8	Fire Team	A2.1	Execute Route	Position Location Information	Squad Ldr	A2.2	Provide PLI Updates	3	Yes	Data	Unclassified
MERS Combat Operations	NL 5	Fire Team	A2.1	Execute Route	Position Location Information	Coalition Forces		External	3	Yes	Data	Unclassified
MERS Combat Operations	NL 8	Squad Ldr	A2.2	Provide PLI Updates	Tactical Commands	Fire Team	A2.3	Coordinate Tactical Maneuvers	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 4	Squad Ldr	A2.2	Provide PLI Updates	Position Location Information	PLT Cmdr		External	2	Yes	Data	Secure
MERS Combat Operations	NL 8	Fire Team	A2.3	Coordinate Tactical Maneuvers	Tactical Situation	Squad Ldr	A2.3	Coordinate Tactical Maneuvers	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Fire Team	A2.3	Coordinate Tactical Maneuvers	Tactical Situation	Squad Ldr	A2.4	Implement Force Protection Measures	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Squad Ldr	A2.4	Implement Force Protection Measures	Command to Fire	Fire Team	A3.1	Employ Weapons	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Fire Team	A3.1	Employ Weapons	Fire Fight Status	Squad Ldr	A3.2	Coordinate Fire Support	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Squad Ldr	A3.2	Coordinate Fire Support	Fire Support Request	Fire Team	A3.3	Assault Enemy Position	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 2	Squad Ldr	A3.2	Coordinate Fire Support	Fire Support Request	FSCC		External	2	Yes	Voice/Data	Secure

Table 24: Operational Information Exchange Matrix (OV-3) (cont.)

Architecture View	Needline ID	Sending Node	Sending Hierarchy ID	Sending Activity	Information Exchange (IE)	Receiving Node	Receiving Hierarch	Receiving Activity	Criticality Code	Criticality	Information Type	Classification Level
MERS Combat Operations	NL 8	Fire Team	A3.3	Assault Enemy Position	Fire Fight Status	Squad Ldr	A4.1	Secure Perimeter	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Squad Ldr	A3.3	Assault Enemy Position	Terminal Weapons Guidance	Fire Team	A4.1	Secure Perimeter	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 7	Squad Ldr	A3.3	Assault Enemy Position	Terminal Weapons Guidance	Airborne Assets		External	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 3	Squad Ldr	A3.3	Assault Enemy Position	Terminal Weapons Guidance	Mech-Armor Support		External	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 1	Squad Ldr	A3.3	Assault Enemy Position	Terminal Weapons Guidance	NSFS Group		External	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 2	Squad Ldr	A3.3	Assault Enemy Position	Terminal Weapons Guidance	FSCC		External	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 8	Squad Ldr	A4.1	Secure Perimeter	Causality Status Request	Fire Team	A4.2	Assess Casualties	5	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Fire Team	A4.1	Secure Perimeter	Ammunition Resupply Request	Squad Ldr	A4.3	Resupply Ammunition	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Fire Team	A4.2	Assess Casualties	Casualtity Report	Squad Ldr	A4.2	Assess Casualties	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 8	Fire Team	A4.2	Assess Casualties	Status of Fire Team	Squad Ldr	A4.4	Convey Situational Status	2	Yes	Voice	Unclassified
MERS Combat Operations	NL 6	Squad Ldr	A4.2	Assess Casualties	MEDEVAC Request	Medical Support		External	2	Yes	Data	Secure
MERS Combat Operations	NL 8	Fire Team	A4.3	Resupply Ammunition	Fire Team Provision Status Report	Squad Ldr	A4.4	Convey Situational Status				
MERS Combat Operations	NL 4	Squad Ldr	A4.4	Convey Situational Status	SITREP	PLT Cmdr		External	1	Yes	Voice/Data	Secure
MERS Combat Operations	NL 4	PLT Cmdr		External	Commander Guidance	Squad Ldr	A2.1	Execute Route	1	Yes	Voice/Data	Secure
MERS Combat Operations	NL 2	FSCC		External	Fire Support Response	Squad Ldr	A3.3	Assault Enemy Position	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 7	Airborne Assets		External	Fire Notification	Squad Ldr	A4.1	Secure Perimeter	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 3	Mech-Armor		External	Fire Notification	Squad Ldr	A4.1	Secure Perimeter	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 1	NSFS Group		External	Fire Notification	Squad Ldr	A4.1	Secure Perimeter	2	Yes	Voice/Data	Secure
MERS Combat Operations	NL 2	FSCC		External	Fire Notification	Squad Ldr	A4.1	Secure Perimeter	2	Yes	Voice/Data	Secure

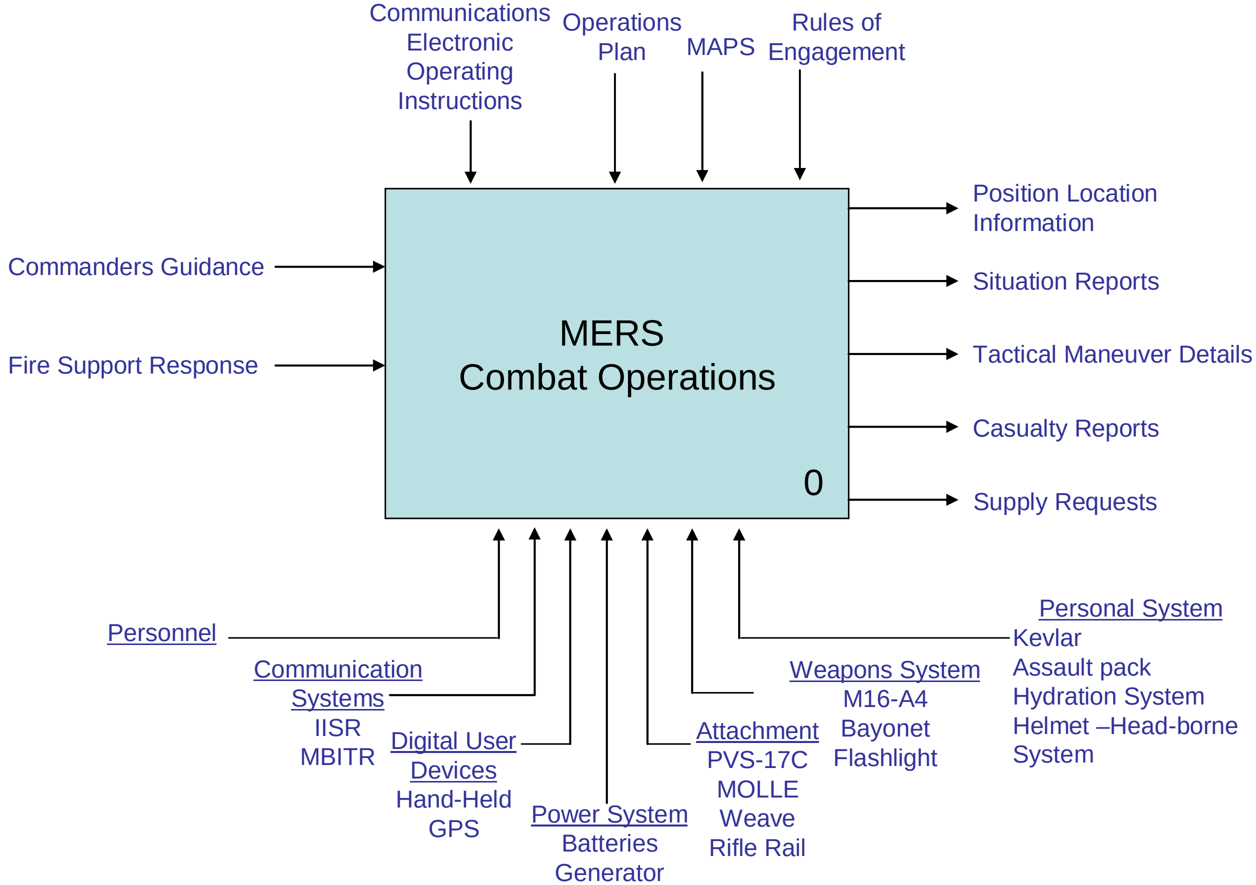

Figure 45: MERS OV-5 Context Diagram

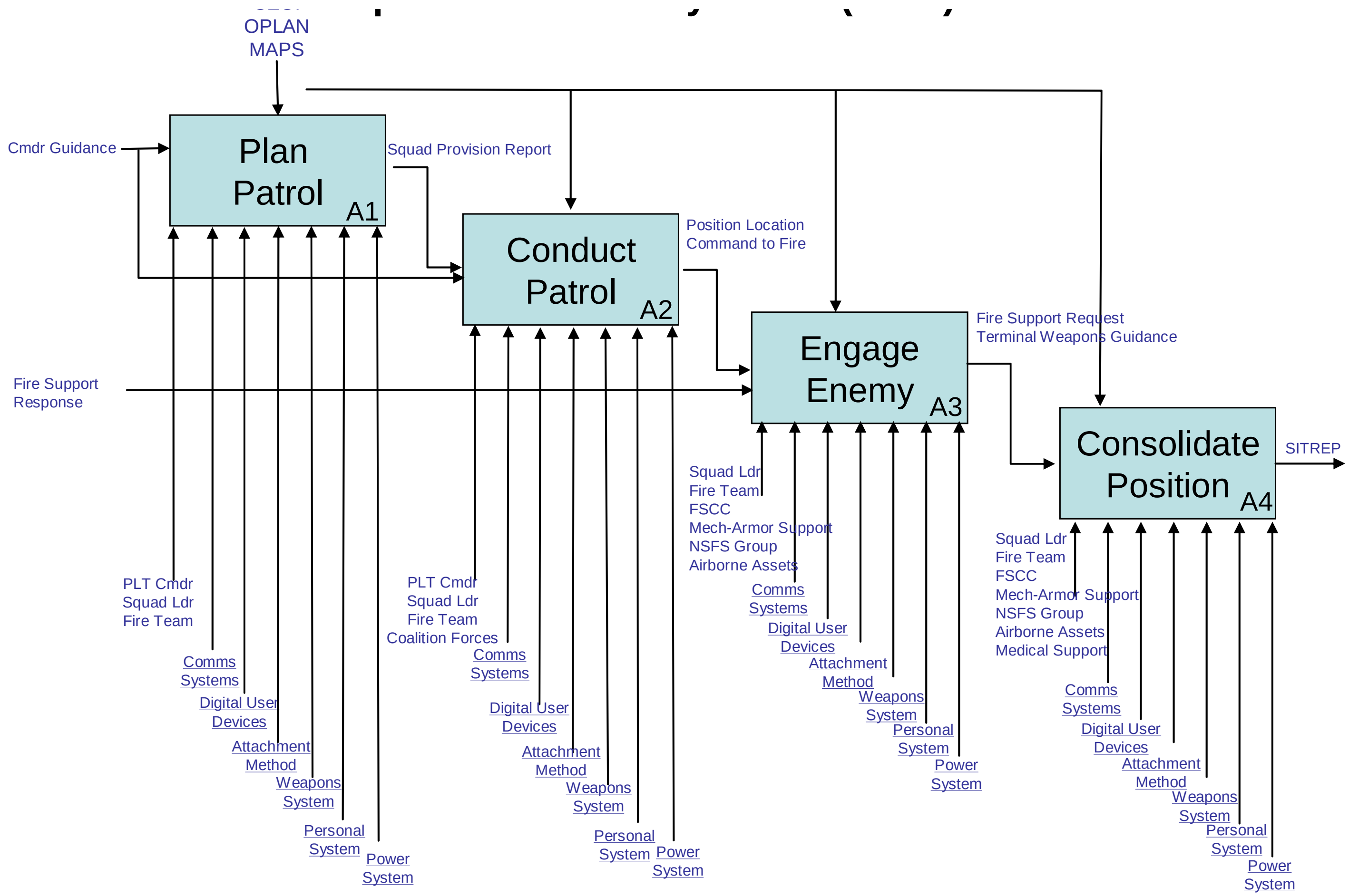

Figure 46: MERS OV-5 Operational Activity Model

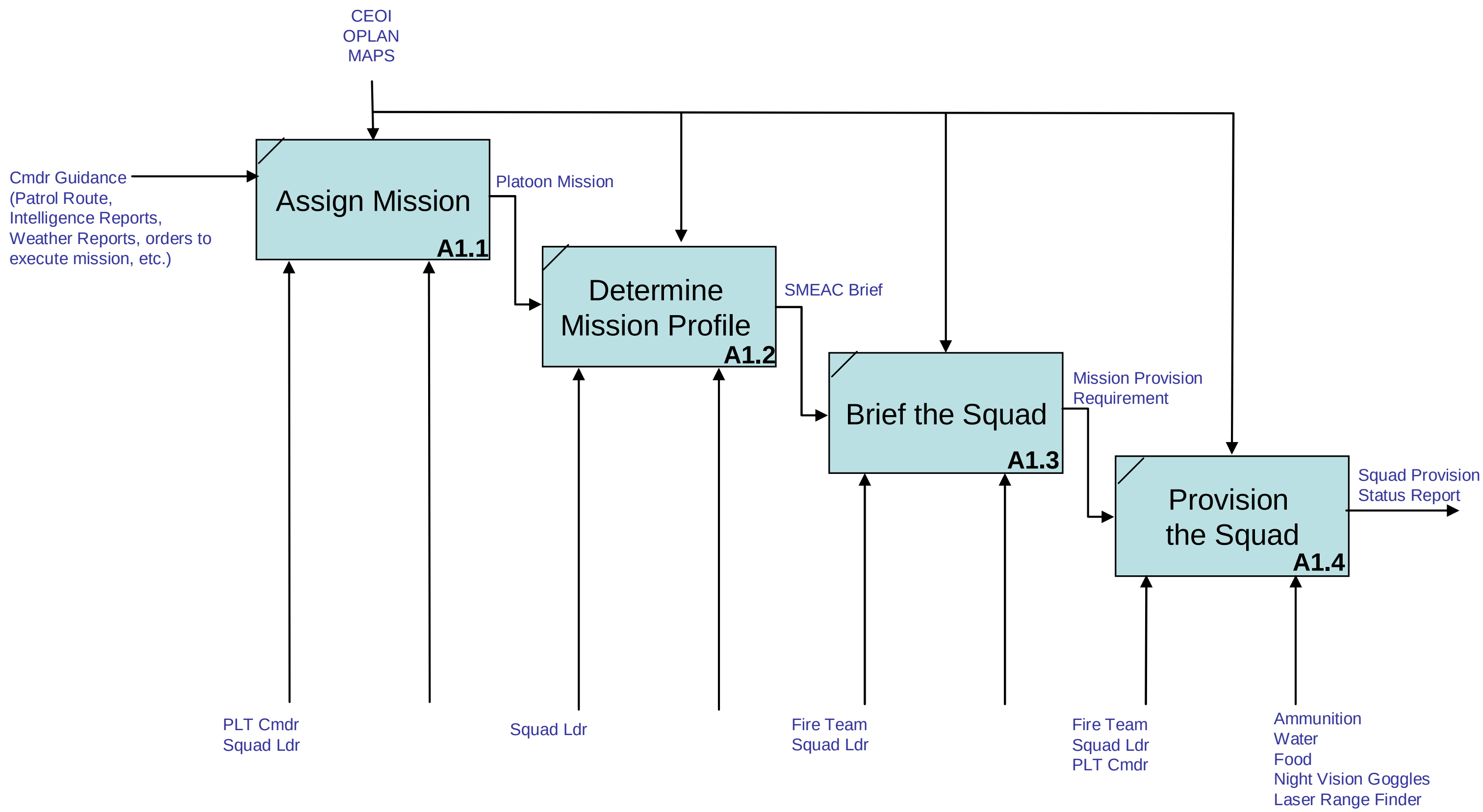

Figure 47: MERS OV-5 Operational Activity Model A1

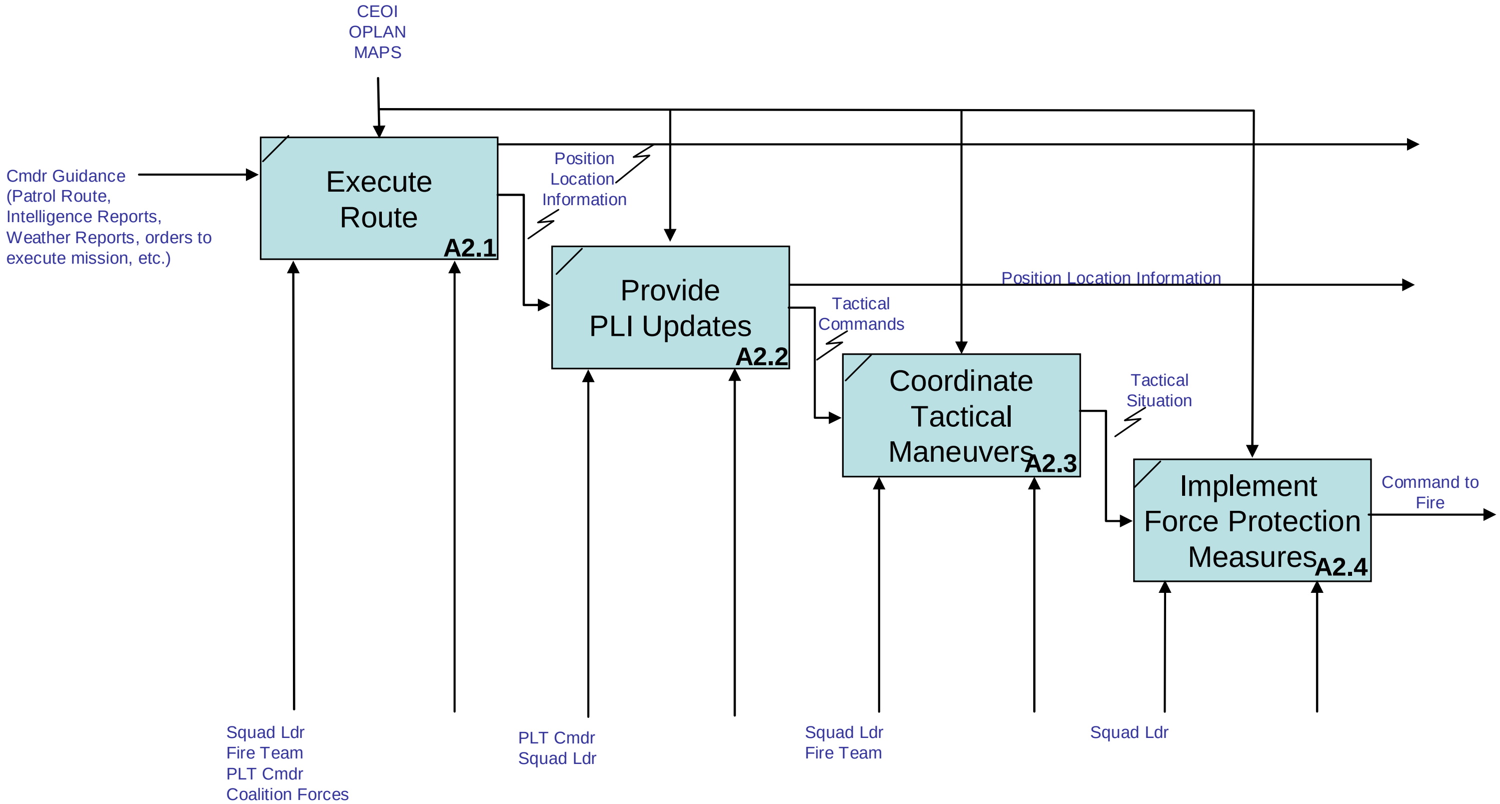

Figure 48: MERS OV-5 Operational Activity Model A2

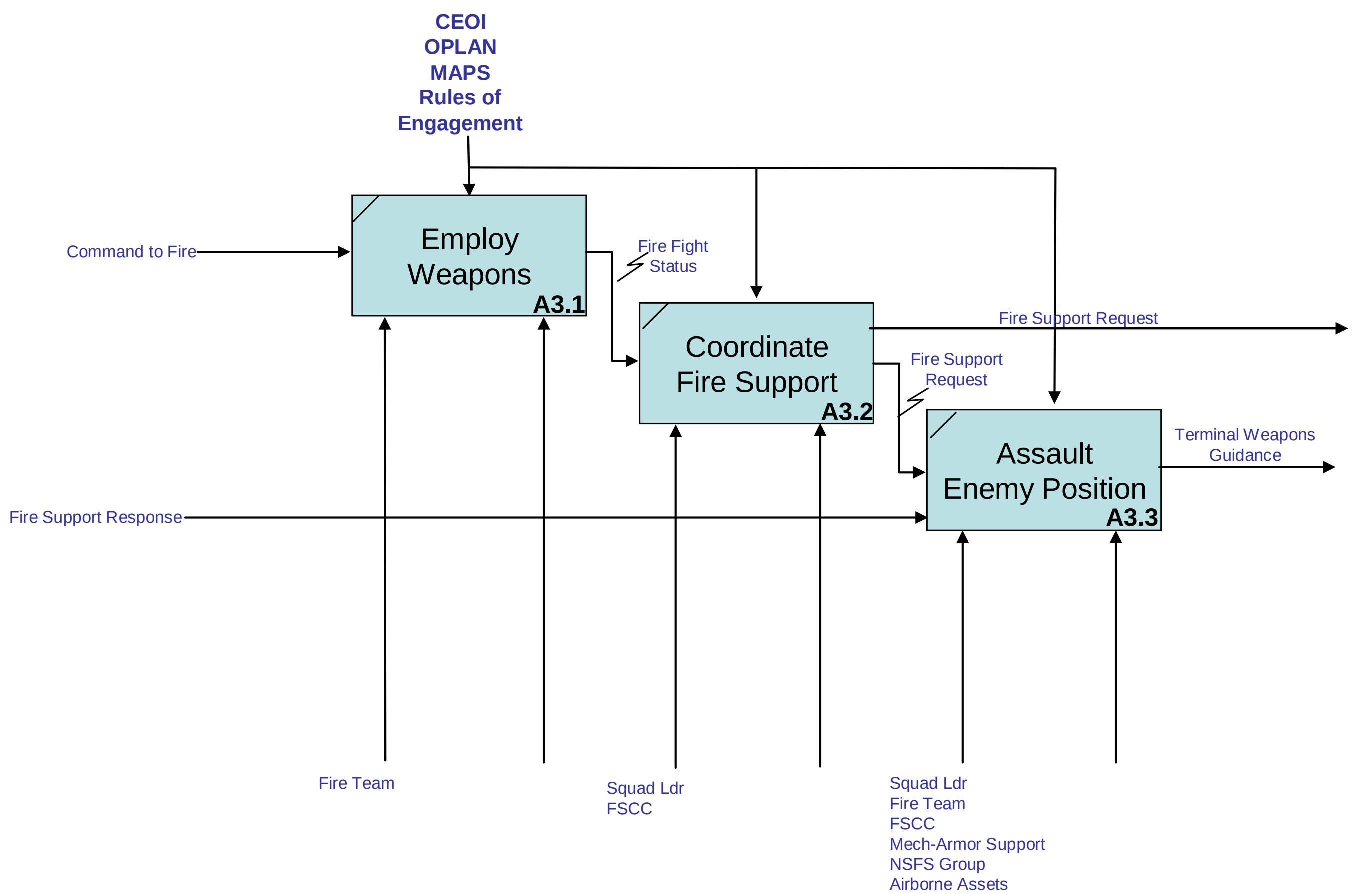

Figure 49: MERS OV-5 Operational Activity Model A3

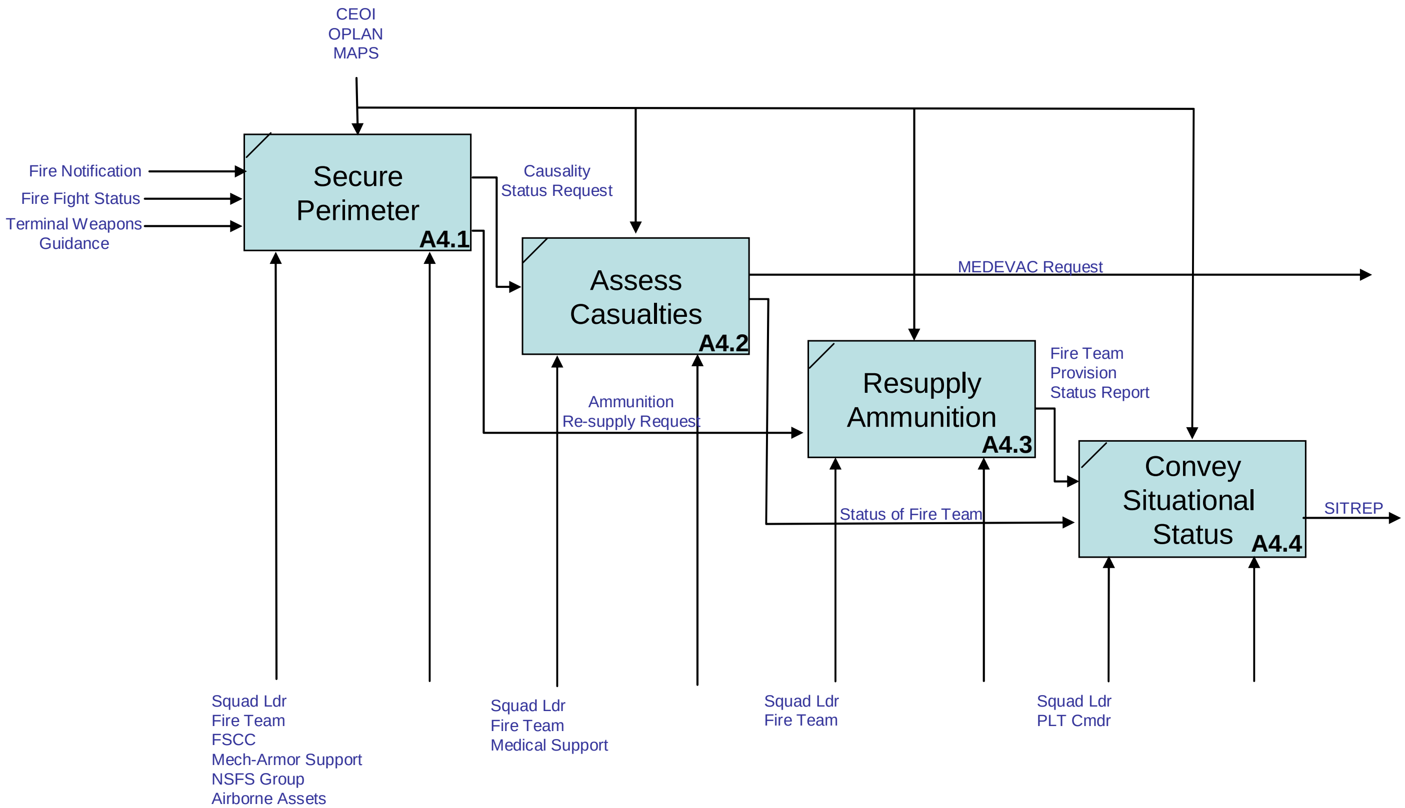

Figure 50: MERS OV-5 Operational Activity Model A3

APPENDIX D

D RIFLE SQUAD COMMUNICATIONS SYSTEM STAKEHOLDER QUESTIONNAIRE

Team Marine categorized Stakeholders in three categories:

- Sponsors/Decision makers
- Clients/end users
- Analysts/Evaluators

<u>Questions for Sponsors/Decision makers included:</u>

- Can a new system be developed and integrated into the Marine Squad?
- Can an "off the shelf" system be used?
- What is the schedule?
- What is the cost?
- Is there funding?
- Can an existing program be used?
- When is the system needed?
- What Tactics, Techniques, Procedures need to be added or revised?

<u>Questions for the Clients/end users</u>

- What are your requirements?
- What are your training requirements?
- Will the system interface with other systems?
- What are the systems, interfaces, and information requirements?
- What information is needed? And who needs it and when?
- What are the skill levels of the members in the squad?
- What types of systems are employed today? What are the "goods" and the bads?
- What capabilities will be fielded soon within the next 12-24 months?

Questions for the Analysts/Evaluators:

- What kind of testing is required?
- What measures will be used?
- Are there Human system interface issues?

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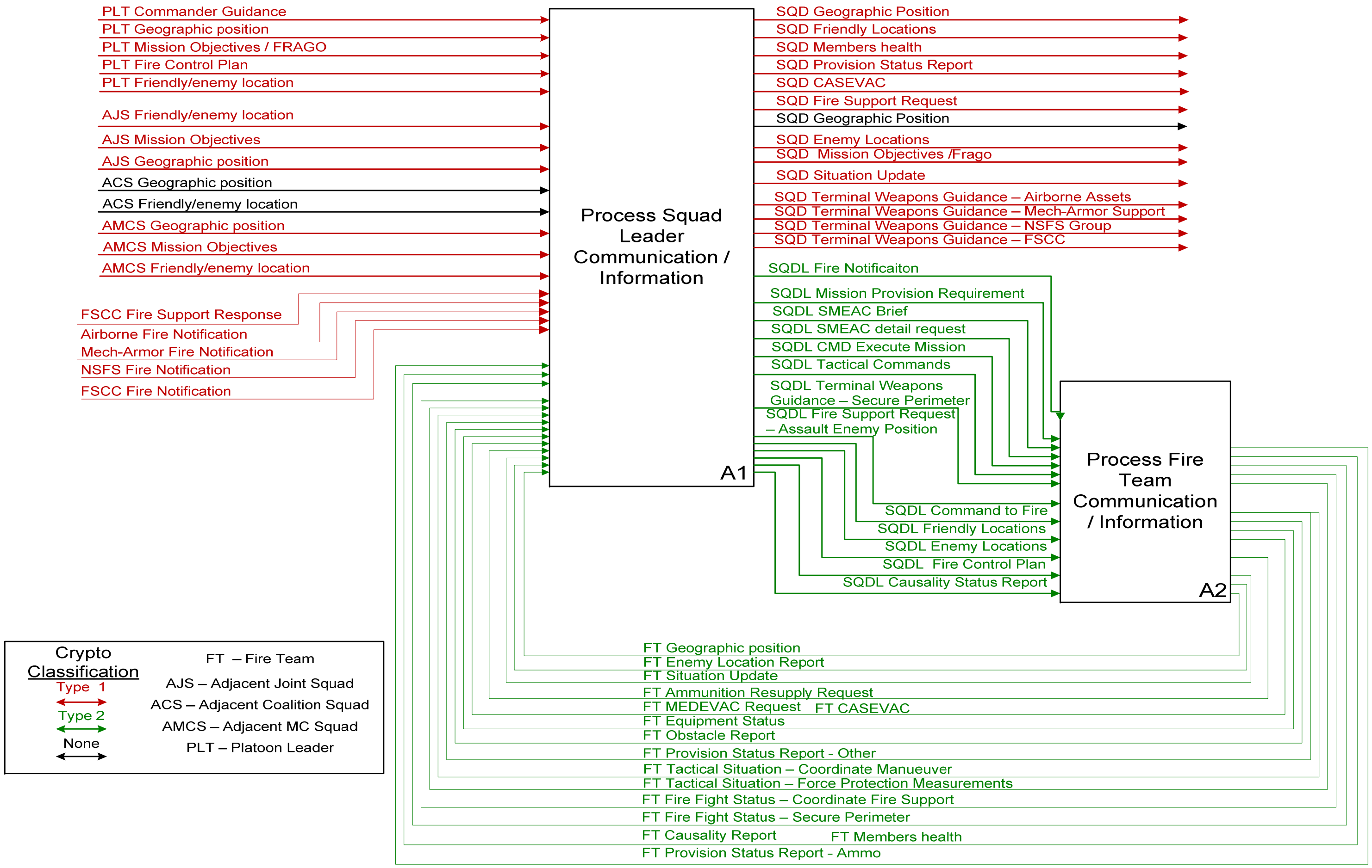
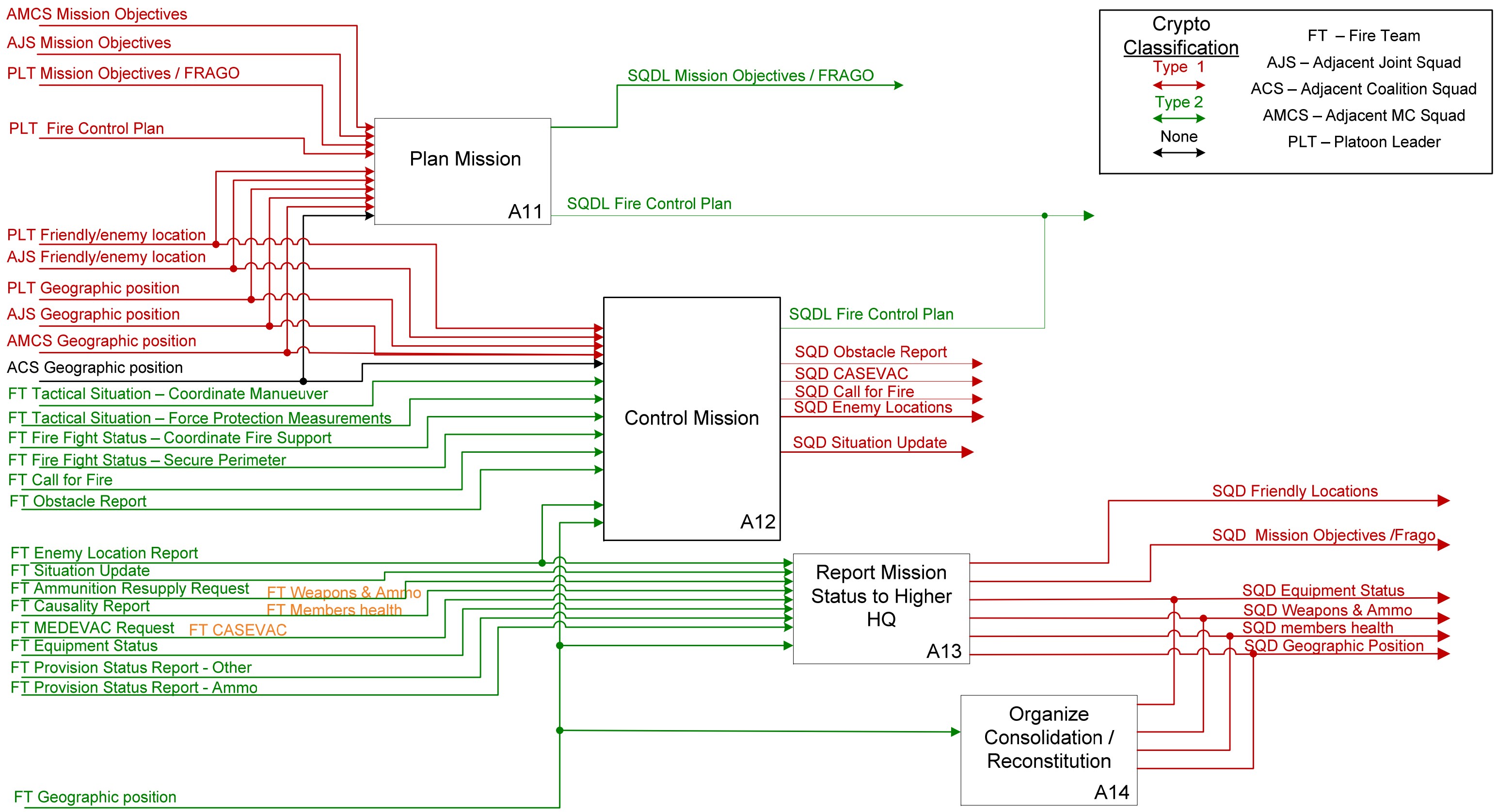
APPENDIX E

E COMMUNICATIONS SYSTEM ARCHITECTURE



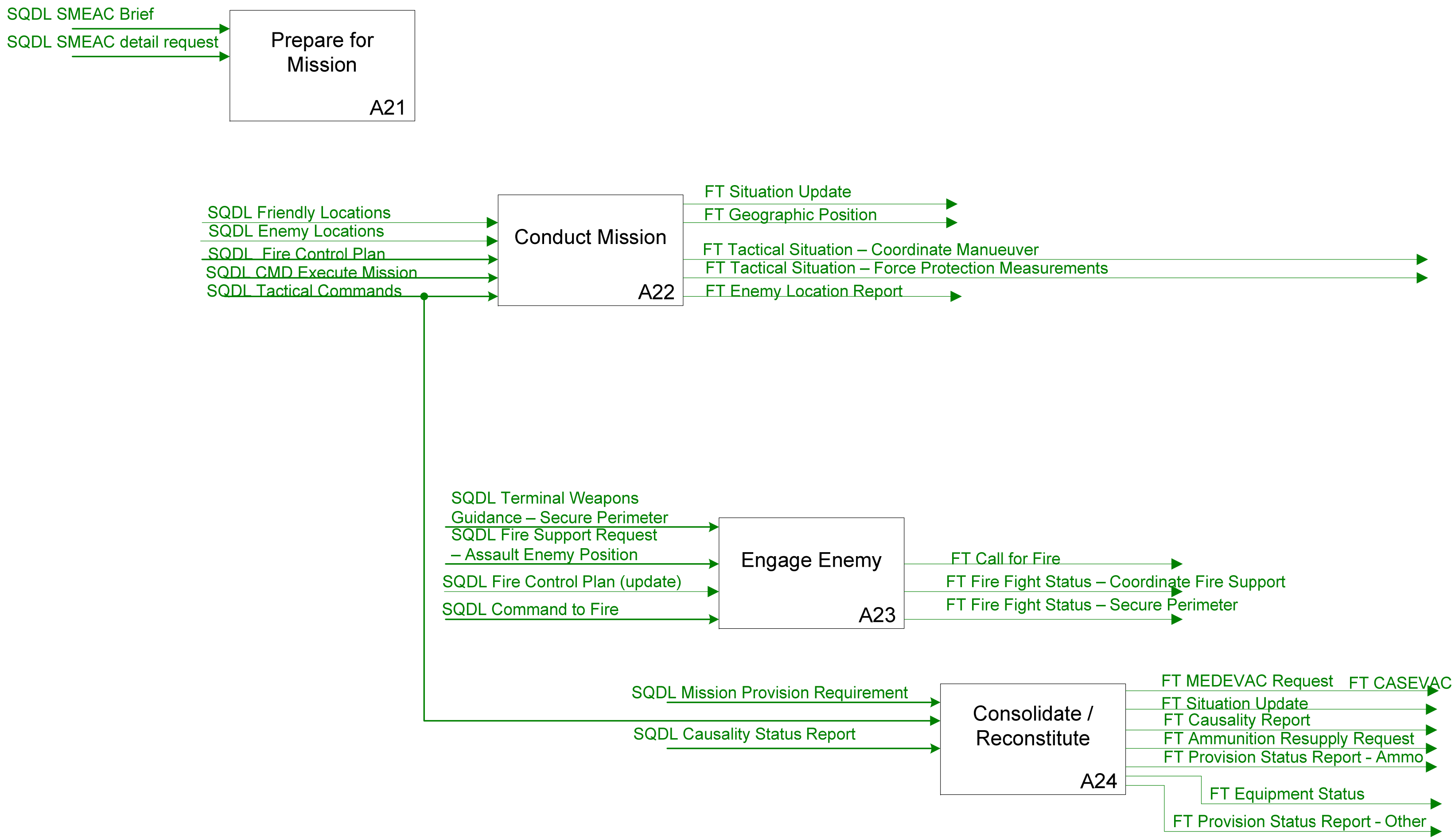
View: Operational	Node: A0	Title: Squad Communications	1 of 1

Figure 51: Squad Communication System Operational View A0



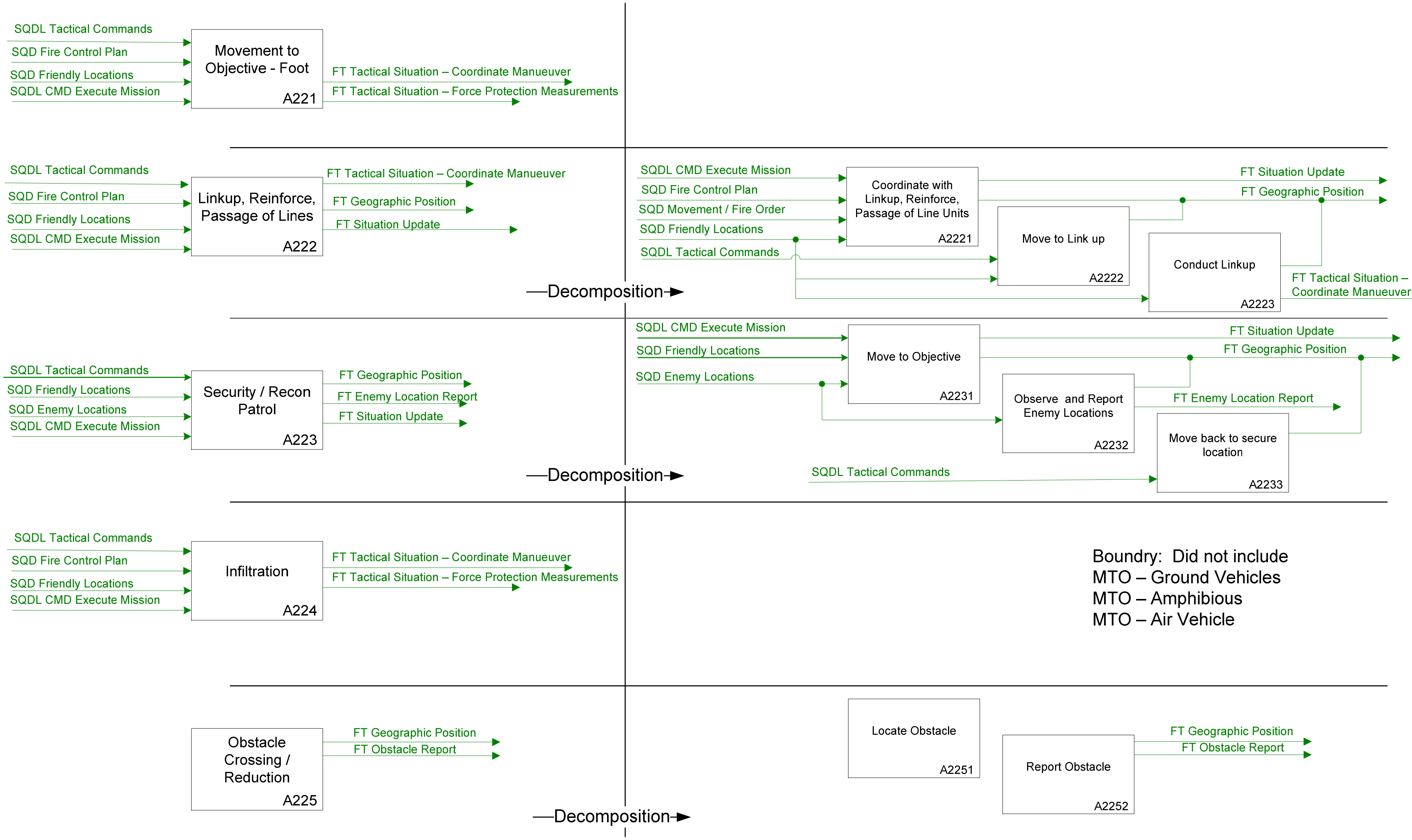
View: Operational	Node: A1	Title: Squad Leader Communications	1 of 1

Figure 52: Squad Communication System Operational View A1



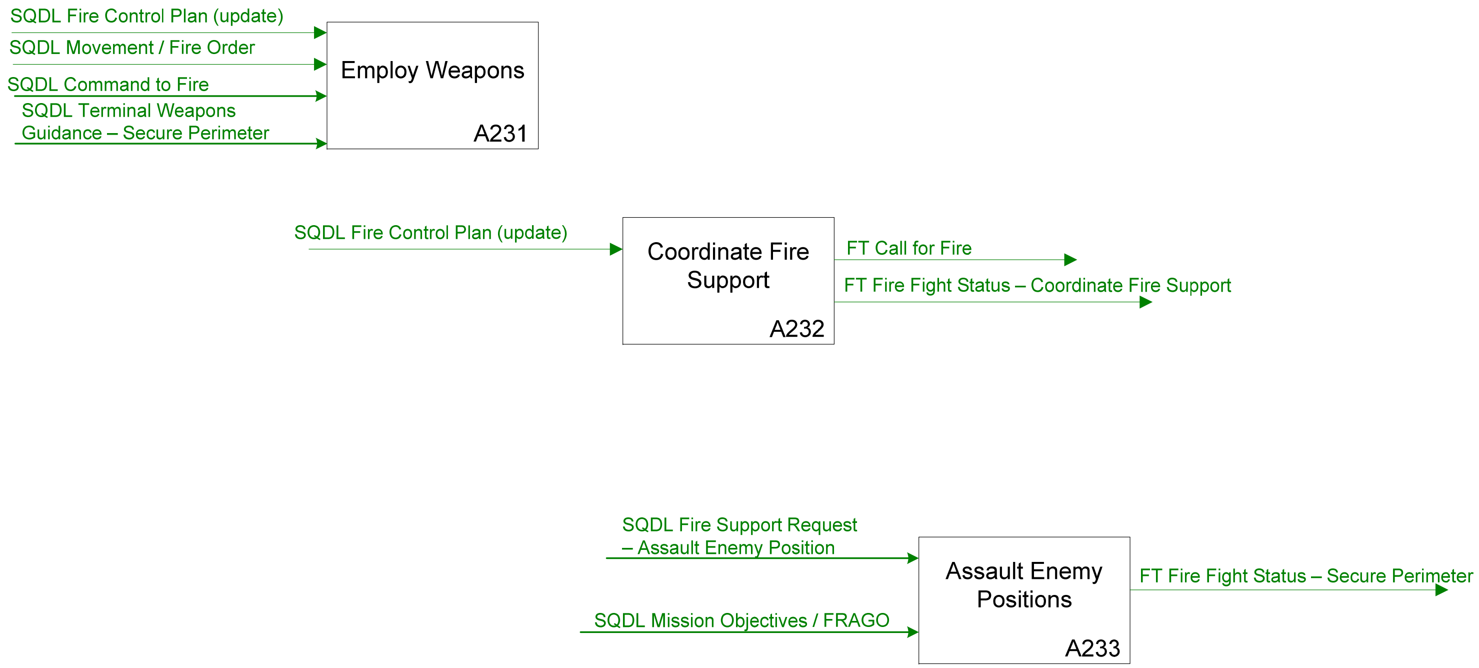
View: Operational	Node: A2	Title: Fire Team Leader Communications	1 of 1

Figure 53: Squad Communication System Operational View A2



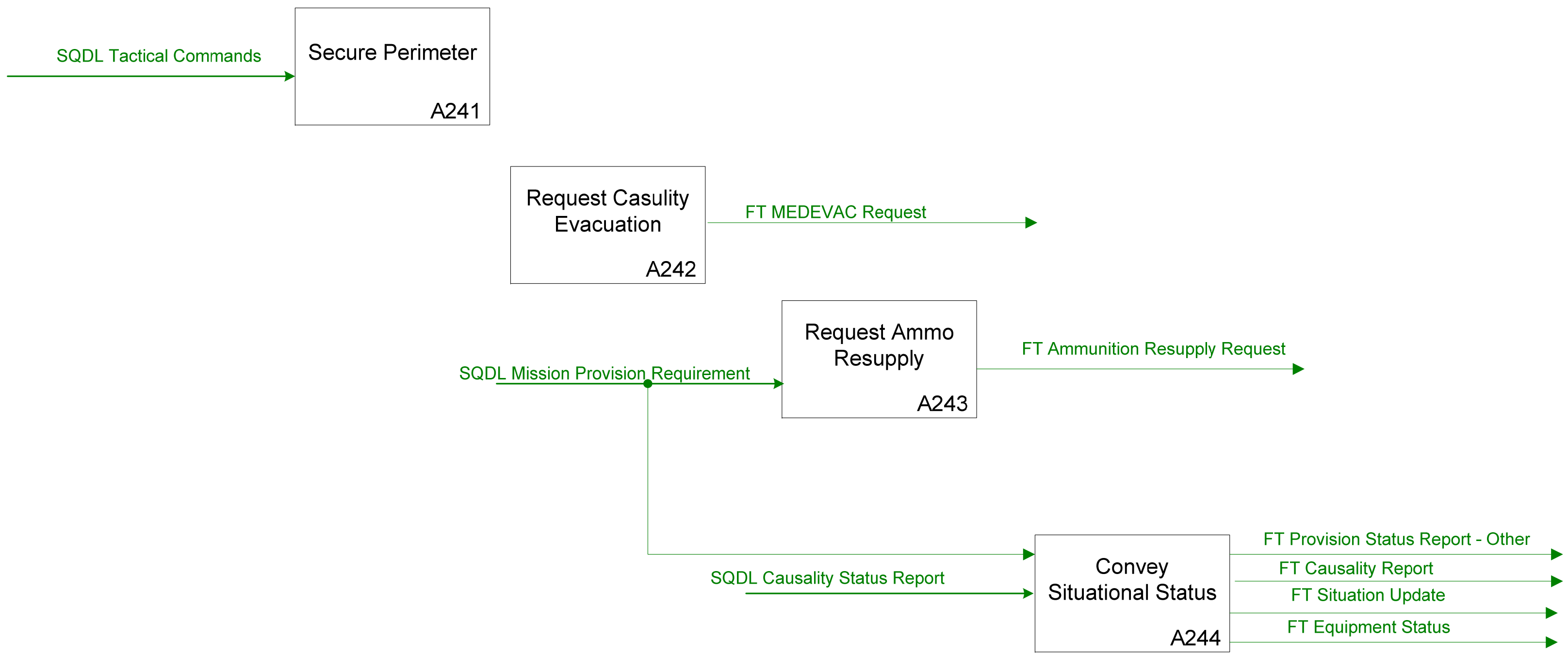
View: Operational	Node: A22	Title: Conduct Mission – Fire Team Leader Communications	1 of 1

Figure 54: Squad Communication System Operational View A22



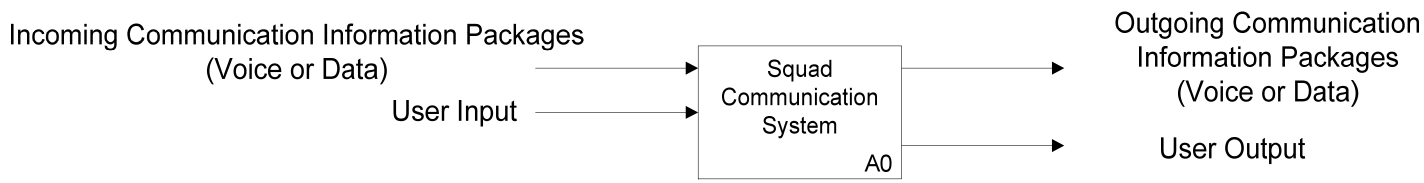
View: Operational	Node: A23	Title: Engage Enemy - Squad Member Communications	1 of 1

Figure 55: Squad Communication System Operational View A23



View: Operational	Node: A24	Title: Consolidate / Reconstitue - Squad Member Communications	1 of 1

Figure 56: Squad Communication System Operational View A24



View: Functional	Node: A-1	Title: Squad Communication System	1 of 1

Figure 57: Squad Communication System Functional View A-1

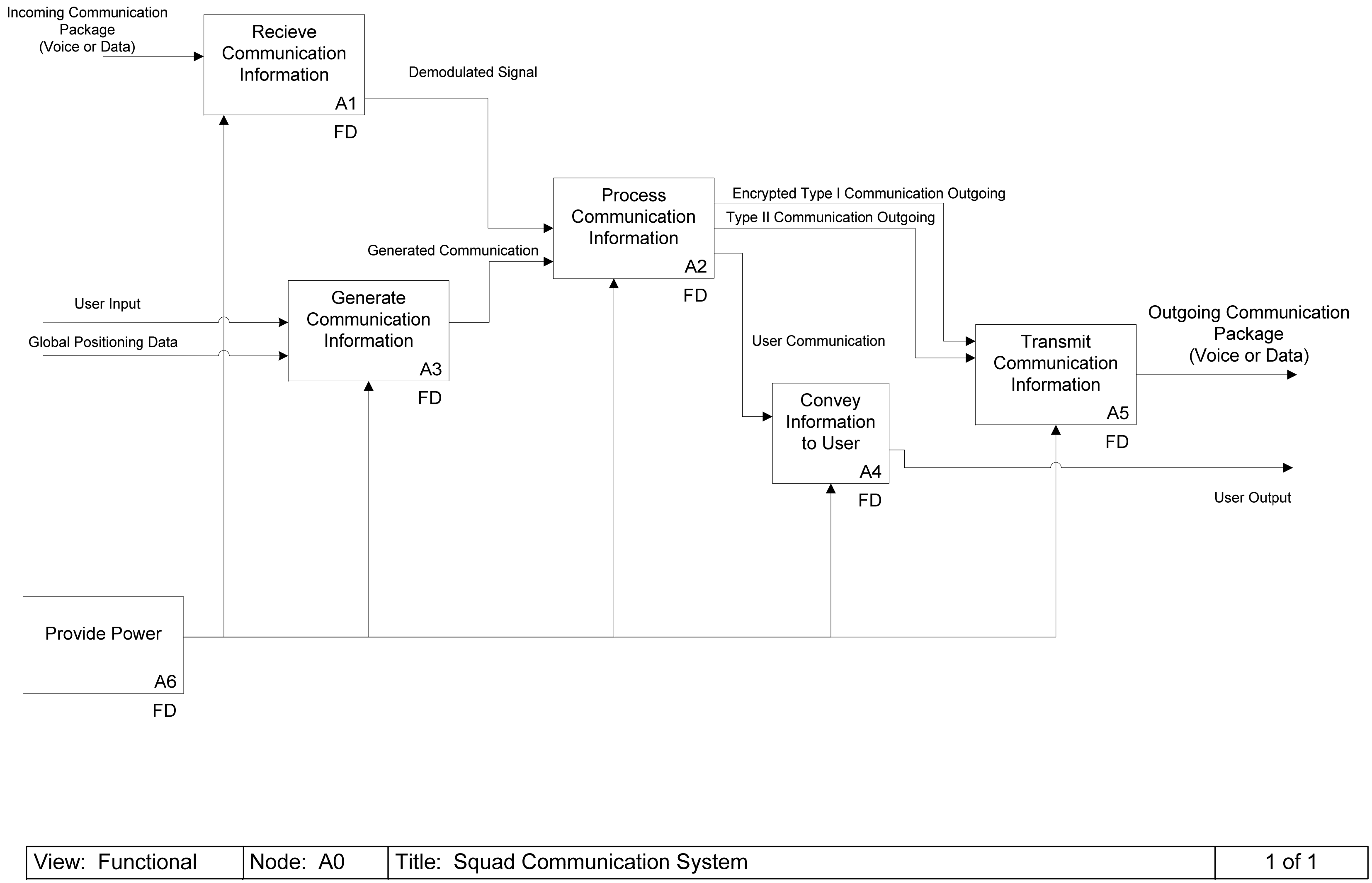
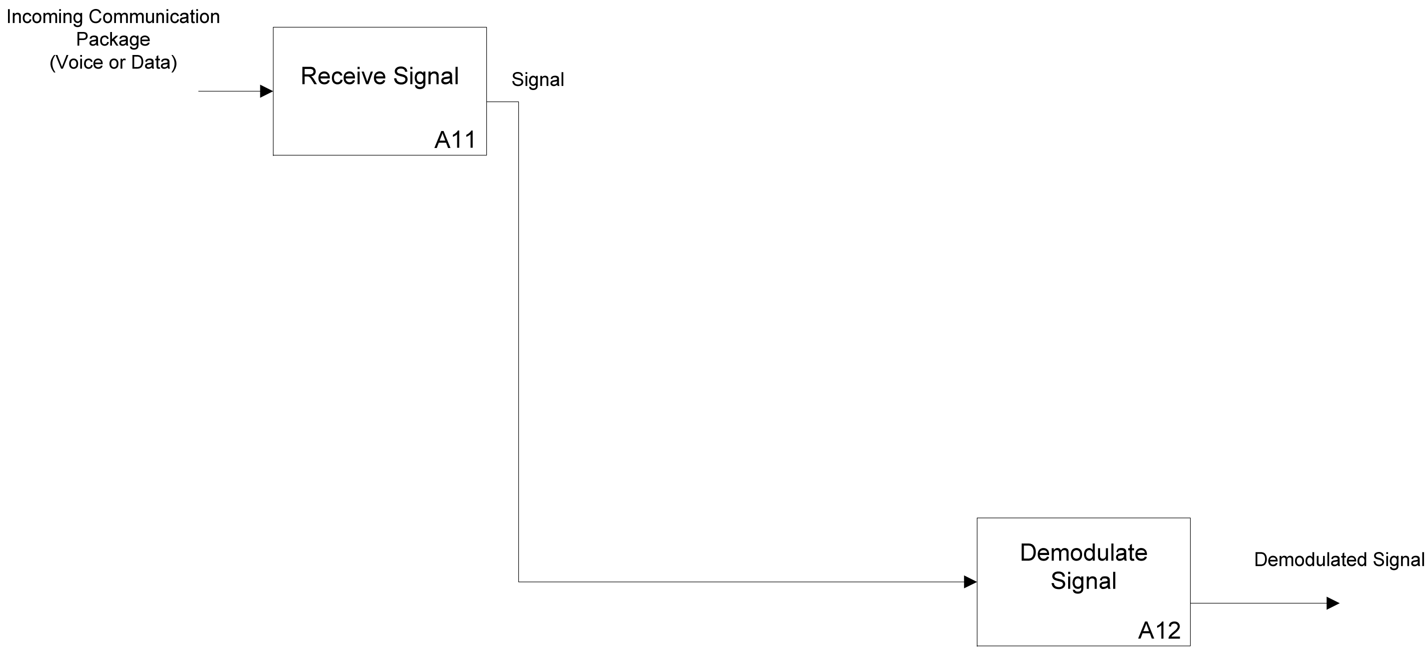


Figure 58: Squad Communication System Functional View A0



View: Functional	Node: A1	Title: Receive Communication Information: Squad Communication System

Figure 59: Squad Communication System Functional View A1

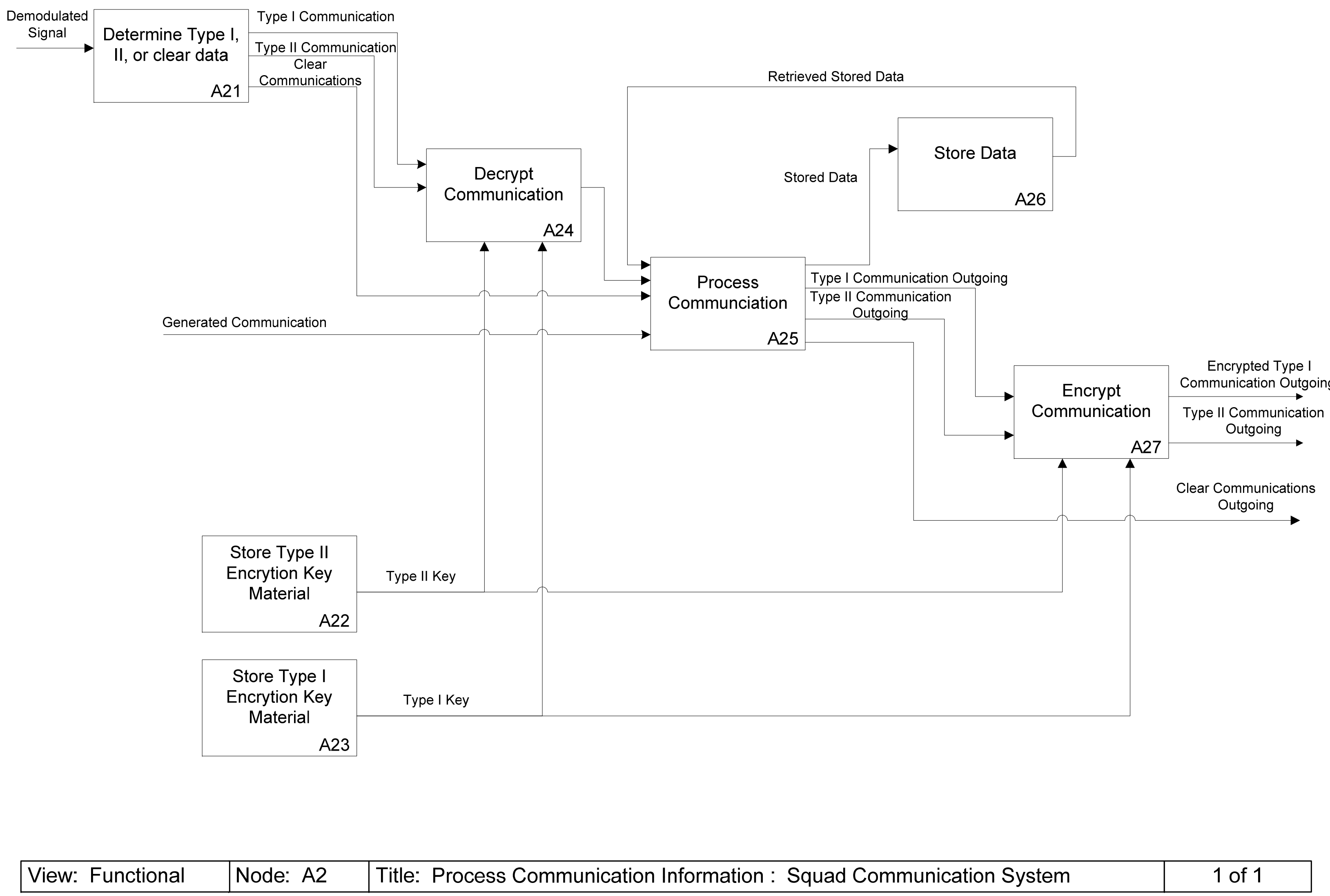
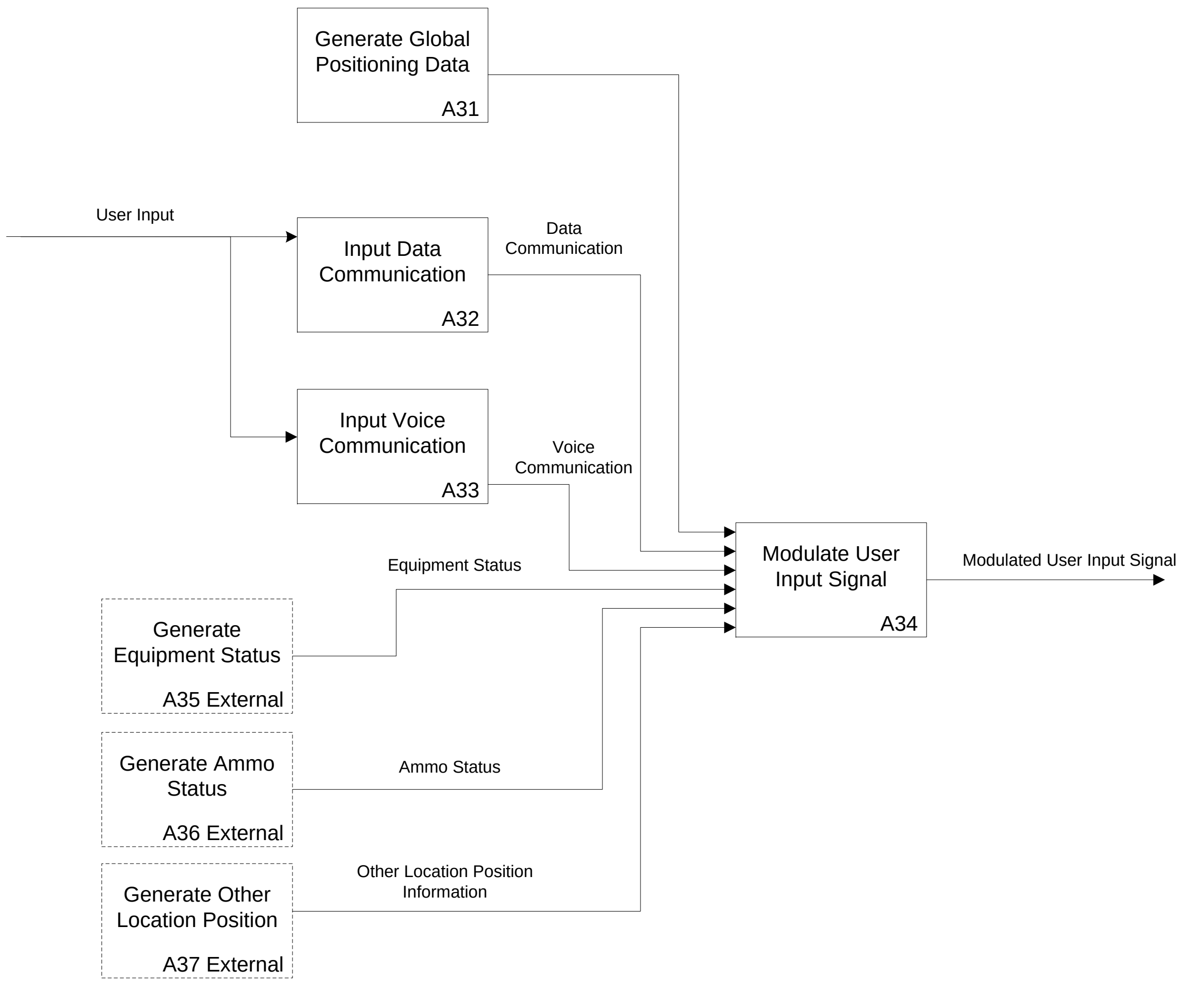
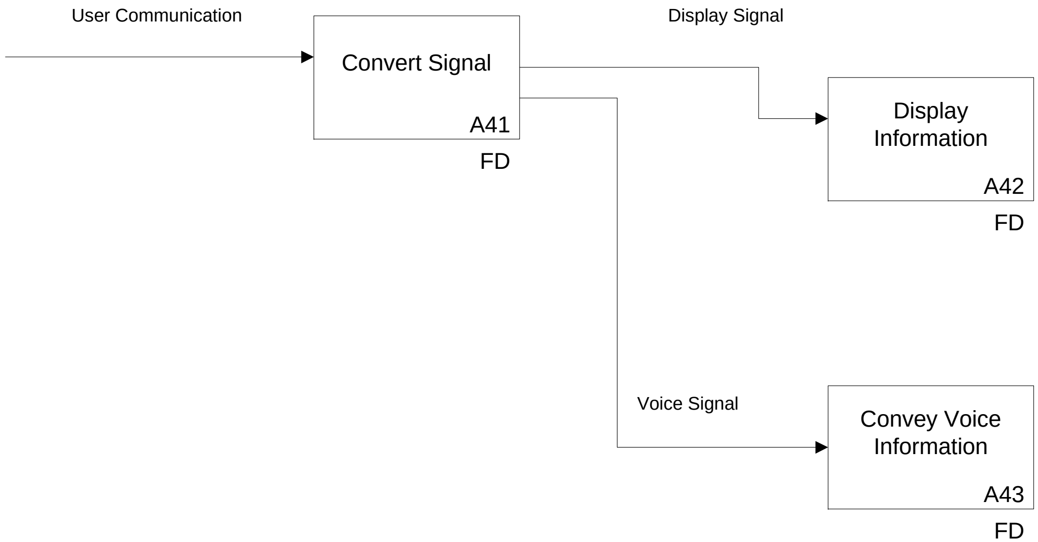


Figure 60: Squad Communication System Functional View A2



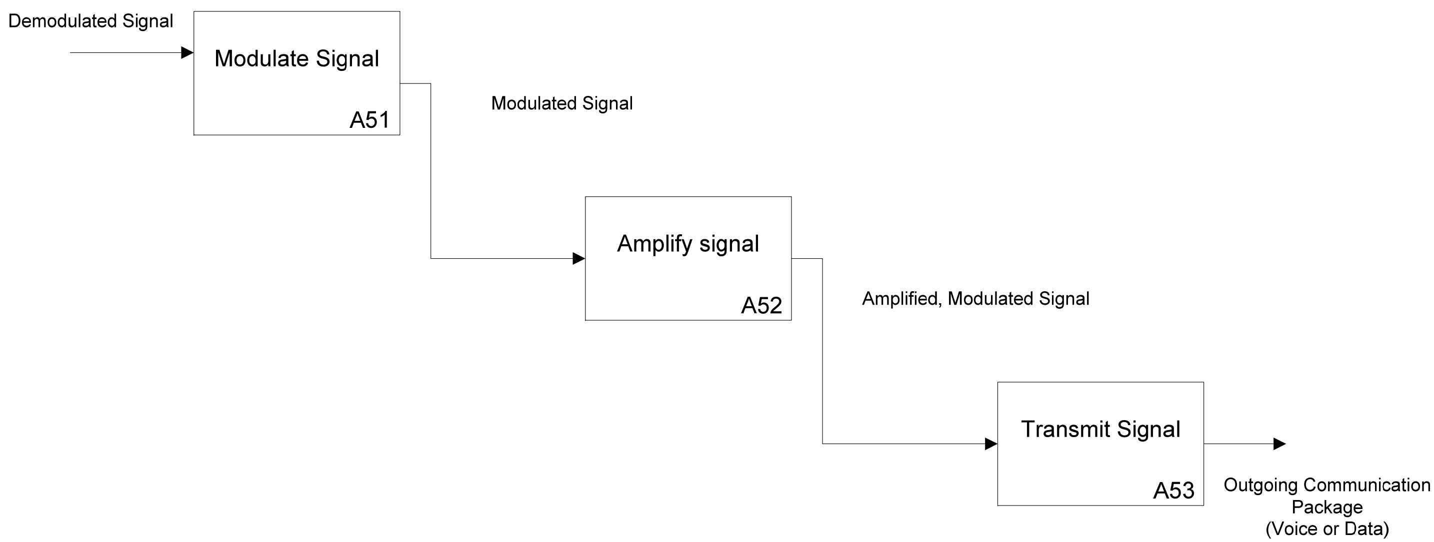
View: Functional	Node: A3	Title: Generate Communication Information: Squad Communication System	1 of 1

Figure 61: Squad Communication System Functional View A3



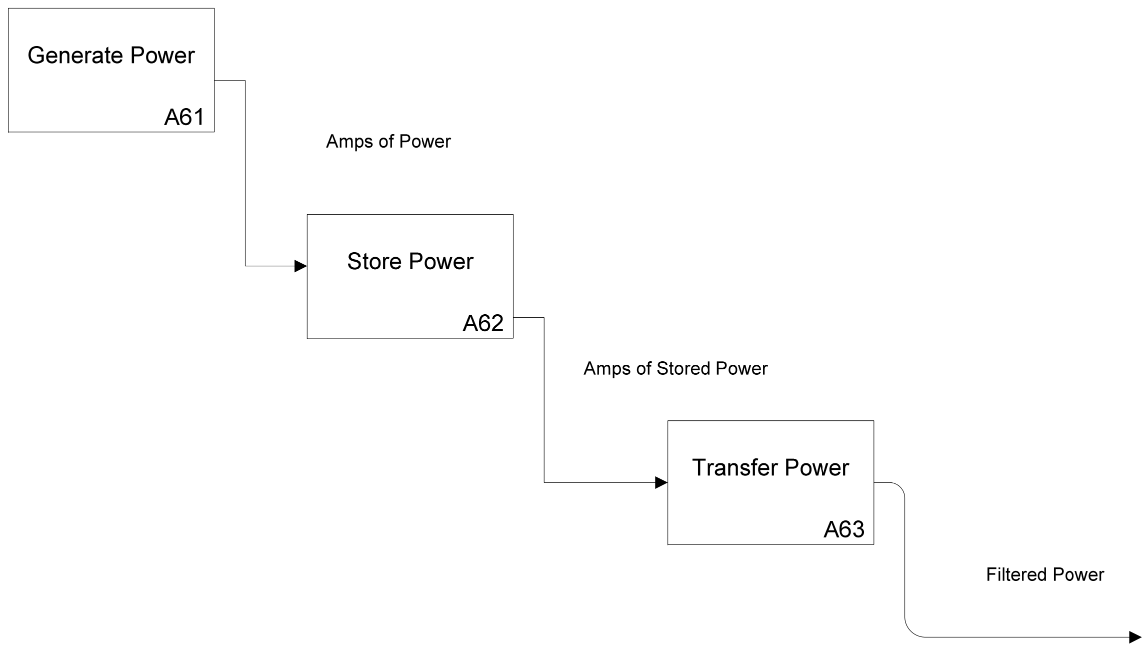
View: Functional	Node: A4	Title: Convey Information to User: Squad Communication System	1 of 1

Figure 62: Squad Communication System Functional View A4



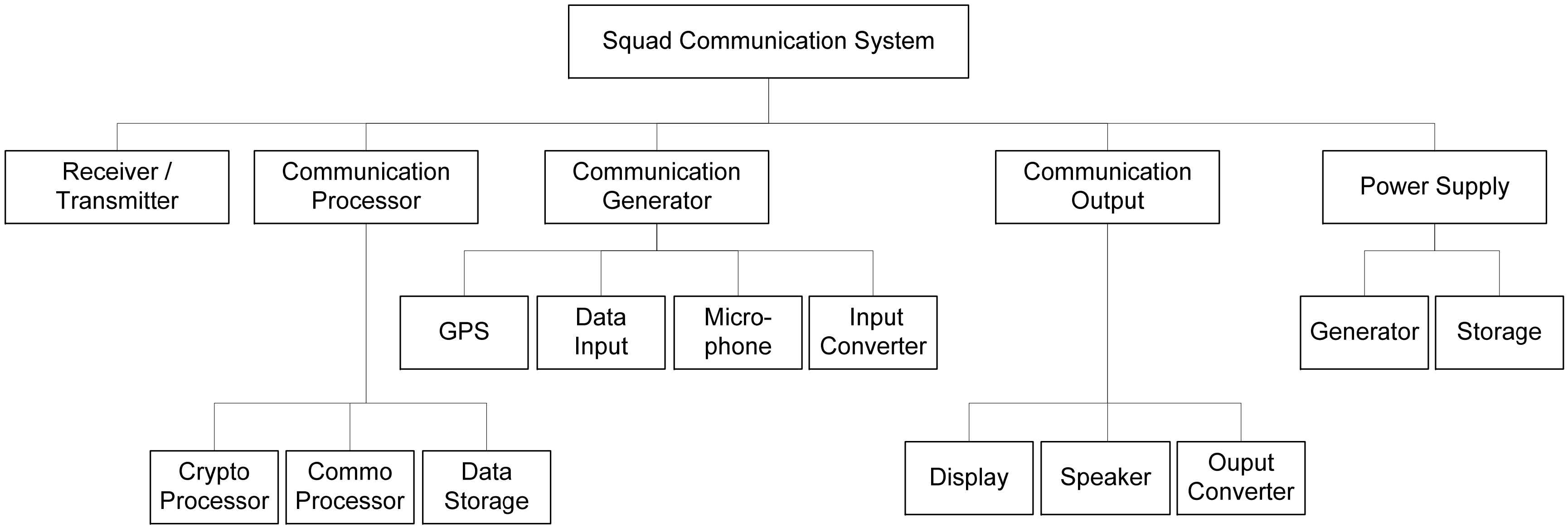
View: Functional	Node: A5	Title: Transmit Communication Information: Squad Communication System	1 of 1

Figure 63: Squad Communication System Functional View A5



View: Functional	Node: A6	Title: Provide Power: Squad Communication System	1 of 1

Figure 64: Squad Communication System Functional View A6



View: Physical	Node:	Title: Physical View: Squad Communication System	1 of 1

Figure 65: Squad Communication System Physical View

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APPENDIX F

F ACKNOWELDGEMENTS

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Our Families (Thank you for your patience!)

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APPENDIX G

G ACRONYM LIST

ACE	Aviation Command Element
BFT	Blue Force Tracker
C2	Command and Control
C4	Command, Control, Communications and Computers
CDD	Capabilities Development Document
COA	Course of Action
COC	Combat Operations Center
CPU	Computer Processing Unit
CTP	Common Tactical Picture
CUI	Controlled Unclassified Information
DC-SIAT	Deputy Commander, Systems Engineering, Interoperability, Architectures and Technology
DODAF	Department of Defense Architectural Framework
DOTMLPF	Doctrine Organization Training Materiel Leadership Personnel and Facilities
ECO	Enhanced Company Operations
FOC	Full Operational Capability
FRAGORDS	Fragmentation Orders
GCE	Ground Command Element
GPS	Global Positioning System
GSE	Ground Soldier Ensemble
HQMC	Headquarters Marine Corps
ICD	Initial Capability Document
IDEF	Integration Definition for Function Modeling
IISR	Interim Intra-Squad Radio
IOC	Initial Operational Capability
IT	Information Technology
JFCOM	Joint Forces Command
JITC	Joint Integrated Test Center
JPO	Joint Program Office
JROCM	Joint Requirements Oversight Counsel Memorandum
JTRS	Joint Tactical Radio System
LCE	Logistics Command Element
MAGTF	Marine Air-Ground Task Force
MCCDC	Marine Corps Combat Development Command
MCOTEA	Marine Corps Operational Test & Evaluation Activity
MCSC	Marine Corps Systems Command
MCWL	Marine Corps War-fighting Laboratory
MEF	MAGTF Expeditionary Force
MERS	Marine Corps Expeditionary Rifle Squad
MOE	Measures of Effectiveness

MSSE	Master of Science in Systems Engineering
MTBF	Mean Time Between Failure
NPS	Naval Postgraduate School
NSA	National Security Agency
OPORDS	Operational Orders
OV	Operational View
PDA	Personal Digital Assistants
PLI	Position, Location Information
PM-MERS	Program Manager for Marine Expeditionary Rifle Squad
POM	Program Objective Memorandum
POR	Program of Record
RR	Rifleman Radio
SA	Situational Awareness
SATCOM	Satellite Communication
SE	Systems Engineering
SEDP	Systems Engineering Design Process
SME	Subject Matter Expert
TTP	Tactics, Techniques and Procedures
USB	Universal Serial Bus
USMC	United States Marine Corps
WARNORDS	Warning Orders

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